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Infrastructure and Urban Development
Department
The World Bank
October 1991
WPS 780

Optimal User Charges and Cost Recovery for Roads in Developing Countries

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and
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What impact do road user charges have on cost recovery? And when they fail to cover total costs, how should the resulting deficit be financed?

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The optimal charge for road use is equal to variable costs for road maintenance, together with the costs road users impose on other road users and on the rest of society (usually confined to the costs of road congestion).

One persistent question raised about such charges is what impact they have on cost recovery. And when they fail to cover total costs, how the resulting deficit should be financed?

The theoretical literature argues that if there are constant returns to scale in road construction and in road use, the optimal user charge will recover the capital costs of the road network and the total expenditures on road maintenance. Empirical estimates for such a system of road user charges in Tunisia similarly suggest that they would generate twice the revenues currently spent on roads. It seems therefore that optimal road user charges would not only recover all costs but would constribute substantially to general fiscal revenues.

Heggie and Fon examine these issues from both theoretical and practical perspectives. They conclude that there are substantial economies of scale in both road construction and road use. Also, road maintenance costs include a number of fixed costs that do not vary with traffic (up to half of annual expenditures on road maintenance are usually fixed). Moreover, since roads cannot be smoothly adjusted to traffic, marginal costs for the entire road network are significantly lower than average costs in most developing countries, unless capacity is artificially constrained by environmental or other constraints. Under these (realistic) conditions, optimal user charges result in a substantial financial deficit.

The question is, how should this deficit be financed?

On roads carrying heavy volumes of traffic, it is not economically efficient to bridge the financing gap by cutting back on maintenance. The gap has to be bridged by collecting the required revenues through user charges, or by mobilizing additional general tax revenues. But the costs of mobilizing additional general tax revenues are high and, given the generally low price elasticity of demand for roads, it is nearly always more economically efficient to collect the required revenues from road users.

It is generally agreed that marginal costs — corresponding to variable road maintenance costs — should be the floor below which user charges should never fall. But there is no reason to stop at marginal costs. An important group of costs are avoidable, attributable to individual groups of users (although not to the individual users themselves), and it seems reasonable — on grounds of simplicity, equity, and political expediency — to charge these costs against the appropriate user group.

The remaining costs, although also avoidable, are common to all users and, to minimize loss of consumer surplus, should be charged to them using the inverse elasticity rule (Ramsey pricing).

Heggie and Fon point out that there are significant differences between current user charges in Tunisia and the user charges calculated using the avoidable cost methodology described in this paper.

OPTIMAL USER CHARGES AND COST RECOVERY FOR ROADS IN DEVELOPING COUNTRIES

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Acknowledgements

The report was prepared as part of a project on Pricing, Cost Recovery and Efficient Resource Use in Transport. It was prepared by Ian Heggie and Vincy Fon (Consultant). An early draft of the report was reviewed by an external panel consisting of Professors William J. Baumol, Princeton University, M. Schankerman, London School of Economics, and Kenneth Small, University of California, Irvine. The report was also reviewed by a group of Bank staff including Philip Blackshaw, EMTIN, Jose Carbajo, INUTD, Ciell Harral, ASTIN, and Vinaya Swaroop, CECPE.

The author would also like to thank the many other World Bank staff and consultants who commented on specific sections of the text, or supplied some of the empirical data presented in the report. They included Jeffrey Gutman, Asif Faiz, Tim Hau, Roy Knighton, Charles J. Lane, Bill Paterson, Sigfus Sigfusson, Rachel Kranton (Consultant), Graham Smith, Rodrigo Archondo-Callao, Pradeep Mitra, Slobodan Mitric, Richard Barrett, Peter Midgley, John Flora, Dick Podolske, and Margaret Callan (Consultant)

The artwork in the report was prepared by Cathy Kocak, GSDAD, and the text was finalized and formatted by Rita Vartanian and Barbara Gregory.

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Executive Summary

i. Current theories of road pricing argue that net economic benefits will be maximized when prices are set equal to short-run marginal costs (variable road maintenance costs and the costs of externalities, usually confined to road congestion). Several empirical studies have claimed to show that such a system of user charges would cover the entire costs of the road network and make a reasonable contribution to overall fiscal revenues. (Paras 1-3).

ii. The above conclusions have been formalized into two theorems: (i) if there are constant returns to scale in road construction and in road use, the optimal user charge will recover the capital costs of the road network and total expenditures on road maintenance; and (ii) if, in addition, heavy vehicles are confined to the outer lanes of roads with four or more lanes and all road damage is attributable to traffic, the optimal user charge will recover the capital costs of the road network and twice total expenditures on road maintenance. (Para 5).

iii. Since roads with four or more lanes comprise less than 10 percent of the road network in most countries, the second proposition has limited application. The paper therefore focusses on the first theorem, applies it to roads in Tunisia and shows that the optimal user charges (as defined by the model) do *not* cover total expenditures on road maintenance and make no contribution to capital costs. The paper then examines how to finance the balance of the unfunded expenditures in the most economically efficient way. The paper does not examine distributional issues, how much road users should contribute to overall fiscal revenues, the choice of pricing instrument, or how pricing strategies affect the costs of supplying roads. (Para 5).

iv. Optimal theories of road pricing are based on a series of explicit and implicit assumptions. They assume: (I) the road network has a fixed length and is subjected to a constant flow of traffic; (II) the road network has a uniform age distribution and the road agency adopts a condition-responsive maintenance strategy; (III) road capacity can be smoothly adjusted to traffic so that the entire road network is in equilibrium; (IV) vehicle operating costs are linearly related to the average roughness of the road pavement; (V) routine maintenance costs are zero; (VI) there are constant returns to scale in road construction; and (VII) there are constant returns to scale in road use (i.e. the time related cost function is homogenous of degree 0). The effect of these assumptions is to ensure that the optimal user charge (levied to cover road damage and congestion costs) exactly covers the annualized costs of the road network and variable expenditures on periodic road maintenance. (Paras 6-21).

v. Assumptions I, II and IV are either reasonable simplifying assumptions, or are unavoidable in the interests of simplifying the analysis, (Paras 23-25). The remaining assumptions are too strong. Periodic maintenance costs do not all vary with traffic; between 20 percent and 65 percent of these costs are fixed (assumption V). Routine maintenance costs likewise are not zero; they account for nearly half total road maintenance costs and an estimated 30 percent are variable. On inter-urban roads there are likewise strongly increasing returns to scale in road construction (assumption VI) and in road use (assumption VIII); on urban roads this is partly offset by rising land values. Finally, roads cannot be smoothly adjusted to traffic (assumption III); they are not infinitely divisible and always operating at their optimal capacity. (Paras 26-29).

vi. When the above assumptions are relaxed, the optimal pricing model breaks down. Relaxation of assumptions V, VI and VII all lead to the same result: when they are relaxed, the optimal user charges fall short of the annualized costs of the road network and total expenditures on road maintenance. In each case, relaxation of the assumption brings in scale economies which leads to attendant deficits when prices are set equal to marginal costs. Finally, assumption III cannot really be relaxed; it follows as a consequence of using differential calculus. It requires that the costs of congestion on each km of road be just equal to the costs of adding a marginal increment in road capacity. This takes no account of the substantial spatial and temporal variations in road traffic and, since indivisibilities are generally recognized to be a source of scale economies, automatically causes deficits when prices are set equal to marginal costs. (Paras 30-36).

vii. When the optimal pricing model is applied to Tunisia, and the costs of urban road congestion are estimated using a traffic simulation model (Annex 2), the resulting user charges only cover just over half the total costs incurred. User charges set on the basis of the above optimal pricing model will therefore leave a large block of expenditures unfunded. (Paras 37-38).

viii. The remainder of the paper considers how to finance these unfunded expenditures in the most economically efficient way. It focusses on roads carrying significant volumes of traffic and considers the options of raising user charges or using general tax revenues (it does not consider taxes on beneficiaries which are normally only relevant on roads carrying low volumes of traffic and primarily providing access to property). The options are examined in terms of their effect on total consumer and producer surplus, with the added consideration that the deficits associated with marginal cost pricing have to be financed. This introduces the costs of general taxation (deadweight and administrative costs) associated with financing these deficits. The conclusion from this analysis is that, provided the administrative costs of road user taxes are similar to general revenue taxes, the welfare costs of marginal cost pricing *plus* general taxation are likely to be higher than the welfare costs of average cost pricing in most developing countries. It follows that a pricing system which raises the extra revenues from users using optimal departures from marginal cost pricing will be more attractive in welfare terms. (Paras 39-44).

ix. The paper introduces the concept of avoidability to classify the costs of operating, maintaining and improving the road network. Three levels of avoidability are identified: (i) costs which are variable and incurred on behalf of identifiable users; (ii) costs which can be avoided over a short period of time and are incurred on behalf of an identifiable group of users (but not the individual member of the group); and (iii) costs which are common to all users and can only be avoided by closing the road network. In Tunisia, these categories account for 29, 26 and 45 percent respectively of total road expenditures. It is suggested that the first group, being marginal, should be recovered from users in terms of veh-km (for variable routine maintenance costs) and **ESA-km** (for variable periodic maintenance costs). Since the second category are avoidable, it is suggested they should be recovered uniformly from the groups on whose behalf they are incurred: in terms of ESA-km (for heavy vehicles) and in terms of PCE-km (to expand road capacity for rural and urban road users). (Paras 45-48).

x. The paper shows that the most economically efficient way of financing the remaining collective common costs, is by using the inverse elasticity rule. This minimizes the relative loss of consumer surplus per dollar of collective common costs covered by each user group. It is done by equalizing the ratios of the mark-up over base-costs (variable and grouped common costs), divided by the sum of the respective supply and demand elasticities, for each user group. The procedure is illustrated in graphical form and is solved using trial-and-error. (Paras 49-52).

xi. The paper also looks at the scope for financing common costs by way of congestion charges. It concludes, based on a review recently completed by the World Bank, that most road congestion in developing countries is attributable to the poor performance of the road agency; it is self-inflicted. The overall conclusions are that: (i) serious road congestion is limited to about twenty large cities in the Bank's developing member countries; (ii) methods of charging for congestion are limited and difficult to administer; and (iii) the charging method selected will be determined by the nature of the city, the administrative complexity of the charging instrument, and its affordability. Since serious (non-self inflicted) congestion is limited in developing countries, it will make little contribution to cost recovery for the road network as a whole. (Paras 53-60).

xii. Finally, the paper applies the above pricing model to Tunisia and concludes that, when the mark-ups are applied to all vehicles, it results in lower charges for cars and much higher charges for all other vehicles. Without pure taxation of freight vehicles (i.e. the mark-ups are applied to passenger vehicles only), the charges for most vehicles are roughly the same. They are, nevertheless, much higher for buses, lower for gasoline cars and higher for heavy trucks. (Paras 61-64).

xiii. The overall conclusions of the paper are: (i) it is unrealistic to assume there are constant returns to scale in road construction and in road use and to ignore routine road maintenance costs; (ii) roads cannot be smoothly adjusted to traffic, so that the marginal costs of the entire road network will usually be lower than average costs; (iii) congestion charges may be justifiable in the limited number of cities experiencing serious road congestion, but the revenues from these charges are unlikely to cover the common costs for the road network as a whole; (iv) it is nearly always more economical to collect the revenues required to cover unfunded road expenditures by raising user charges using to the inverse elasticity rule (rather than by using general tax revenues); and (v) there are significant differences between current road user charges in Tunisia and those calculated using the above avoidable cost methodology. (Paras 65-66).

I. INTRODUCTION

1. Economists have repeatedly urged governments to "get prices right" or, more strongly, have argued that "getting prices right [might not be] the end of economic development, but getting prices wrong frequently is" (Meier, 1983, pp. 1 and 231; Timmer, 1987, p. 39). Prices influence resource allocation, revenue mobilization and the distribution of income; they provide the indispensable information needed to reach rational economic decisions on what and how much to produce. To maximize net economic benefits, prices should be set equal to the social external costs directly attributable to a small increase or decrease in output, i.e., equal to short-run marginal costs. In the case of roads, these prices (or optimal user charges) are equal to the value of the resources consumed when using the road. They consist of the damage done to the road surface (variable road maintenance costs) and the additional costs (usually confined to congestion costs) which each user imposes on other road users and on the rest of society (Walters, 1968; Churchill, 1972).

2. One of the persistent queries raised by the above pricing rule is what impact it has on cost recovery and, when it results in deficits, how these should be financed. One of the seminal works on road user charging reached the following conclusion, "on the rural and interurban highways, the revenue collected from user charges at marginal costs is likely to be insufficient to cover the (annualized) investment cost of the roads; whereas in the case of congested city streets it is likely that the revenue from marginal cost pricing will be more than sufficient to meet the total costs". It also argued, however, that "we find that there are no grounds for requiring a particular road, a class of roads, or the highway system as a whole to cover its costs by user charges" (Walters, 1968, p. 114). On the other hand, the author also claimed there was no overwhelming presumption that such user charges would necessarily result in large deficits. This was an empirical question and the only way to test the consequences of using optimal user charges was to calculate them to see whether they resulted in deficits.

3. Initial results from calculating such charges were encouraging. A rough calculation for Thailand during the 1960s suggested that optimal user charges would have raised existing road user revenues from between \$40 and \$50 million p.a. to over \$60 million (Walters, 1968, pp. 226-227) and a more detailed study of five countries in Central America concluded that "the net impact of these changes [in road user charges] would be to raise public revenues from user taxes by 32 percent to 50 percent, depending on the country" (Churchill, 1972, p. 3). Recent estimates for Tunisia likewise suggest that optimal user charges would generate twice the revenues currently spent on roads (Newbery et al, 1988). These results are nevertheless critically dependent on the estimated costs of congestion and there are reasons to believe that some of the estimates were too high. A more cautious approach results in estimates of optimal user charges which are significantly lower.1/

1/ Walters, 1968, bases his estimate on the costs of congestion on urban highways in the UK (pp. 178 and 226) where average per capita GNP was nearly thirteen times that in Thailand. Estimated travel time costs, and hence the yield of a congestion tax, may therefore be too high. Newbery, et al, 1988, likewise assume all urban traffic in Tunisia is congested and assume very high marginal time costs. Annex 1 of this paper suggests the estimates for Tunisia may also be too high.

4. The theoretical literature is also ambiguous about the impact of marginal cost pricing on cost recovery. An early analytical model showed that an optimal pricing and investment strategy would be exactly self-financing if there were constant returns to scale in road construction. When there were decreasing returns it would earn a surplus, while if there were increasing returns it would incur a deficit (Mohring and Harwitz, 1962). The model nevertheless ignored road maintenance costs and was recognized as being too simplistic. A more recent model has overcome some of these objections and has arrived at the following two propositions: (i) if there are constant returns to scale in road construction and in road use, then the optimal road user charge will recover the capital costs of the road network and the total expenditures on road maintenance; and (ii) if, in addition, heavy vehicles are confined to the slow lanes (i.e., the outer lanes on roads with four or more lanes) and all road damage is attributable to traffic, the optimal user charge will recover the capital costs of the road network and twice the total expenditures on road maintenance.

5. The second proposition has limited application, since few countries have many four-lane roads. In the U.S.A., only 8.4 percent of the paved road network (excluding local roads) have four or more lanes and the proportion in Japan is 3.5 percent, Mexico 3.5 percent and Tunisia 1.0 percent. These roads usually carry between 5 to 10 percent of total traffic. Engineers furthermore take account of differential use when designing road pavements. The following paper therefore concentrates on the first proposition, applies it to the road network in Tunisia (as described in Newbery et al, 1988) and shows that the optimal user charges do not cover the total expenditures on road maintenance and make no contribution to capital costs. The paper then examines ways of recovering these costs in the most economically efficient manner. It is also important to say what the paper does not do. It does not deal with the impact of pricing policies on income distribution, does not examine what contribution the road sector might be expected to make to overall fiscal revenues, has not dealt with the choice of charging instrument (i.e., whether, and how, to use licence fees, fuel taxes, sales and excise taxes, import duties, etc. to collect road user revenues) and does not deal with noise, air pollution and other externalities. It likewise does not deal with the important relationship between the choice of pricing strategy and the impact this has on management incentives and hence on the costs of supplying road services.

II. OPTIMAL PRICING MODEL

6. In their attempt to derive optimal road user charges, Mohring and Harwitz (1962) considered the problem of maximizing long-run net benefits. Net benefits, NB, equal consumer private benefits minus total costs. Consumer private benefits, PB(N), are a function of the number of trips, or level of traffic, N, and can be represented as the area underneath the demand curve.2/ Total costs, TC(N,w), are assumed to depend on the level of traffic N and highway capacity w, a function of the width of the road measured in number of lanes of standard width. The TC function has two components. The first is users' total costs, N·VV(N,w). The term VV, the time-cost function per trip, or the vehicle operating cost (VOC), increases with increases in N and with decreases in w. The second component of TC is the capital expenditure for roads and is written r·KK(w) where r is the interest rate for public investments and $KK_w(w)$ > zero.3/ Note that this formulation of costs omits all road maintenance costs. The problem here is to choose the optimal level of traffic N and capacity w to maximize net benefits:

$$\begin{aligned} \text{Max } NB &= PB(N) - TC(N,w) \\ &= PB(N) - [N \cdot VV(N,w) + r \cdot KK(w)] \end{aligned}$$

7. In this formulation, the marginal private benefits of the trip, MPB_N are given by the derivative of PB(N). The marginal social costs of the trip, MSC_N, or the additional social costs due to an additional trip, are given by the partial derivative of TC(N,w) with respect to N, which is equal to the partial derivative of N·VV(N,w) with respect to N, or, [VV(N,w) + $N \cdot VV_N(N,w)$]. Since VV is the VOC borne by users, it is the marginal private cost of the trip, MPC_N. Since $N \cdot VV_N(N,w)$ denotes the additional congestion costs imposed on other users from one more trip, we call this the marginal external costs of the trip, MEC_N. Therefore, we see that MSC_N equals $MPC_N + MEC_N$. The net marginal costs of highway capacity are given by the partial derivative of TC(N,w) with respect to w, which is equal to $N \cdot VV_w(N,w) + r \cdot KK_w(w)$. The term $N \cdot VV_w(N,w)$ is negative and denotes the decrease in time-costs when highway capacity is expanded; it therefore represents benefits to users. We will refer to $-N \cdot VV_w(N,w)$ as the marginal private benefits of expanding capacity, MPB_w. The term $r \cdot KK_w(w)$ represents additional road costs and will be called marginal road costs of expanding capacity, M_RC_w. To conclude, the net marginal costs of highway capacity are equal to marginal road costs of capacity minus marginal private benefits of capacity, or, $[M_RC_w - MPB_w]$.

8. The optimal levels of traffic and highway capacity must satisfy the first-order conditions for maximizing net benefits. These conditions are found by equating the partial

2/ The notation used in this paper is closer to that of Newbery (1987).

3/ We shall abuse the standard mathematical notation for partial derivatives by also using it to denote derivatives.

derivatives of **NB** with respect to N and w to zero. With the help of the notation introduced above, we can easily see that the conditions are as follows:

$$\mathbf{MPB_N = MSC_N = MPC_N + MEC_N} \qquad (1)$$
$$\mathbf{MPB_w = M_RC_w}. \qquad (2)$$

In words, equation (1) says that the marginal private benefits from an additional trip should be equated to the sum of private VOCs (**VV**) and the marginal external costs of this trip (due to congestion). Equation (2) says that the marginal private benefits of additional capacity (due to reduction in time costs) should be equated to the marginal costs of additional highway capacity.4/

9. From the maximization condition (1), we see that in order to have an efficient highway system, the external costs from congestion must be internalized. That is, an appropriate congestion charge equal to $\mathbf{MEC_N}$ should be levied. The remaining question is to find out when revenue from congestion charges will cover the road costs. Assume that **VV** is homogeneous of degree 0 in N and w, meaning that doubling both traffic and highway capacity leaves VOCs unchanged, and that **KK** is homogeneous of degree 1 in w, meaning that there are neither economies nor diseconomies of scale in highway construction. Under these assumptions, the optimal user taxes would be just sufficient to cover all road costs. Since this model will be generalized and discussed carefully later, we defer the explanation of cost recovery until then.

10. Because road width, w, does not enter the demand function directly and only influences total costs, the problem of maximizing net benefits decomposes into two stages. For any given N, minimize total costs of supplying that N. This yields the optimal highway capacity w^* as a function of N, $w^* = g(N)$.5/ Then in the second stage, solve: Max **PB(N) - TC(N,g(N))** to find the optimal amount of traffic

11. Specifically, an efficient highway system can therefore be found by first solving the total cost minimization problem:

$$\mathbf{Min\ \ TC = N \cdot VV(N,w) + r \cdot KK(w)} \qquad (3)$$

to find the optimal highway capacity, assuming that the level of traffic N is constant. This means that the partial derivative of **TC** with respect to w must be set to zero, giving $\mathbf{MPB_w = MRC_w}$, as in equation (2) . Since $\mathbf{MPB_w}$ depends on w as well as N, one must make sure that the level of traffic N is also optimal. This means that N must satisfy equation (1). Or,

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4/ It should be noted that the first-order conditions (1) and (2) are only necessary but not sufficient. Mohring and Harwitz implicitly assumed the existence of the second-order sufficient conditions.

5/ In practice, the first-order condition, (2), for total cost minimization may not present w as an explicit function of N. With the help of Implicit Function Theorem, w^* can indeed be thought of as a function of N.

MPB_N must be made equal to MSC_N by imposing a congestion charge of MEC_N. In general, to describe the efficient highway system, it is sufficient to investigate the problem of minimizing total costs and applying MEC_N as the optimal tax. In fact, this approach was adopted by Newbery (1987), who extends the model of Mohring and Harwitz (1962) by incorporating maintenance costs.

12. The following presents the essence of Newbery's model mathematically. It contains three important implicit assumptions: (i) the road network has a fixed length and is subjected to a constant flow of traffic per lane (assumption I); (ii) the road network has a uniform age distribution and the highway agency adopts a condition-responsive maintenance regime (assumption II); and (iii) road capacity can be smoothly adjusted to traffic, so that the entire road network is in equilibrium (assumption III). These assumptions, together with the explicit mathematical assumptions made in this section, are discussed in section 3.

13. Newbery considers the problem of minimizing total costs when choosing an optimal highway capacity **w** with pavement strength **S**. There are three parts to the total cost function. First are the VOCs, which consist of overhead costs v_0, time related costs per km **V**, and wear and tear to the vehicle. Item **V** is an increasing function of traffic flow **N** and a decreasing function of highway capacity **w**. That is, we have $V(N,w)$ with $V_N > 0$ and $V_w < 0$. The wear and tear on the vehicle is assumed to be linearly dependent on average roughness, written as **bR**, where **b** is positive and **R** represents average roughness (assumption IV). Therefore, the total vehicle operating costs to all users are $N \cdot (v_0 + V(N,w) + bR)$.

14. The second component of total costs are the annualized costs per kilometer of road construction. It is specified as a function of highway capacity **w** and strength **S** and is written as $r \cdot [K_0 + wK(S)]$, where **r** is the cost of funds, K_0 is a non-negative constant and $K_S > 0$. When K_0 is zero, the construction costs corresponds to the case of constant returns to expanding road capacity, holding road strength constant.6/ The case of increasing returns to scale is reflected in K_0 being positive.

15. The last component in the total costs are the annual maintenance costs per kilometer, $w \cdot M(D/w,S)$, where D/w represents the number of equivalent standard axles (ESAs) per unit of capacity and the maintenance cost function per lane **M** is an increasing function of D/w, and a decreasing function of **S**. That is, $M_{D/w} > 0$ and $M_S < 0$. The term **D**, the number of heavy axles, is assumed to be $N \cdot E$, the total traffic flow **N** times the vehicles' average damaging power **E**.7/ Road maintenance costs, **M**, are assumed to consist of periodic

6/ When K_0 is zero, $r \cdot w \cdot K(S)$ in this model extends the capital investment function $r \cdot KK(w)$ in the previous model when KK is homogeneous of degree 1 by incorporating an additional variable S.

7/ We simplify Newbery's model by assuming that there is only one type of vehicle. If many types of vehicles are considered, then D is the sum of the product of traffic flow of each type of vehicle and the respective average damaging power of this type over all types.

(resurfacing) costs only. Routine maintenance is ignored (assumption V). Note that in this formulation, road maintenance costs omit fixed maintenance costs and any maintenance costs which may depend on the volume of traffic, rather than on the passage of heavy vehicles.

16. The road system is optimally designed by first choosing values of capacity w and strength S to minimize total costs:

$$\text{Min } TC = N\cdot[v_0+V(N,w)+bR] + r\cdot[K_0+wK(S)] + w\cdot M(D/w,S). \quad (4)$$

By taking the partial derivatives of TC with respect to w and S and equating them to zero, we have the minimization conditions:8/

$$N\cdot V_w + r\cdot K + M + w\cdot M_{D/w}\cdot(-D/w^2) = 0 \quad (5)$$
$$r\cdot w\cdot K_S + w\cdot M_S = 0. \quad (6)$$

Rewriting equations (5) and (6), we have

$$-N\cdot V_w = r\cdot K + M - (D/w)\cdot M_{D/w} \quad (7)$$
$$-w\cdot M_S = r\cdot w\cdot K_S. \quad (8)$$

17. The left-hand side of (7), representing the reduction in user time-costs due to an additional lane, is the marginal private benefit of capacity MPB_w. The first two terms on the right-hand side of (7) represent the increased costs of adding capacity, since K is the road construction costs per unit of capacity and M are the variable periodic maintenance costs of that unit of capacity. The last term in (7) represents the reduction in periodic maintenance costs per unit of capacity since an additional unit of capacity reduces the number of heavy axles per unit of capacity and hence decreases the total periodic maintenance costs of the road. The three right-hand terms sum to become the marginal costs of adding an additional unit of capacity; they can also be written as $r\cdot K + M(1 - \xi)$, where ξ is the elasticity of M with respect to D/w. Equation (7) therefore prescribes that for an optimally designed roadway, the marginal benefit of adding capacity should equal the marginal costs of capacity. For this conclusion to be meaningful, it must be assumed that road capacity can be smoothly adjusted to traffic (as per assumption III).

18. Likewise, the left-hand side of (8) represents the marginal benefits of additional strength through a reduction in periodic maintenance costs (M_S is negative), and the right-hand side of (8) represents the marginal increase in road construction costs due to additional strength. Equation (8) then prescribes that an optimally designed roadway should choose the strength of roads appropriately so as to equate marginal benefits of strength with marginal costs of strength.

8/ In the following, we suppress the arguments of all functions to facilitate the understanding of various conditions. Like Mohring and Harwitz, Newbery implicitly assumed the existence of the second-order sufficient conditions.

With these interpretations, one can easily see why equations (7) and (8) extend equation (2) in the previous simpler model.

19. To ensure that the right level of traffic N is induced, the marginal external costs must be internalized through taxes, as was mentioned earlier. To determine the road tax, we need to know the marginal social costs of traffic MSC_N, which is the partial derivative of TC with respect to N. In this case, we have:

$$MSC_N = [v_0 + V(N,w) + bR] + N \cdot V_N + E \cdot M_{D/w}. \qquad (9)$$

The first three terms consist of the VOCs and represent the user's marginal private costs MPC_N. The term $N \cdot V_N$ represents the external costs imposed on other road users through congestion. The last term $E \cdot M_{D/w}$, which is the simplification of the partial derivative of $w \cdot M$ with respect to N, or, $w \cdot M_{D/w} \cdot (E/w)$, represents the additional periodic maintenance costs caused by the additional traffic. Hence the last two terms together become the marginal external costs of traffic, MEC_N, or,

$$MEC_N = N \cdot V_N + E \cdot M_{D/w}. \qquad (10)$$

As noted before, MEC_N, is the efficient road tax for each user. In fact, it is readily seen that the unit congestion charge should be $N \cdot V_N$ and the unit road damage tax should be $E \cdot M_{D/w}$. Note how equation (9) extends the right-hand equality in equation (1).

20. To extend his analysis, Newbery assumes constant returns to scale in road construction with respect to capacity, holding road strength constant, so that $K_0 = 0$ (assumption VI). He also assumes that the time related cost function V is homogeneous of degree 0 (assumption VII).9/ By definition, V homogeneous of degree 0 means that:

$$V(\alpha N, \alpha w) = \alpha^0 \cdot V(N,w) = V(N,w).$$

The above equation says that doubling traffic and highway capacity ($\alpha = 2$) leaves the time related costs V the same. That is, as far as the users' time-costs are concerned, it is the average traffic per unit of capacity not the absolute amounts of traffic and capacity, that counts. In other words, measured in terms of user time-costs, additional capacity is the same as the average capacity. By Euler's equation, V homogeneous of degree 0 implies that:

$$N \cdot V_N + w \cdot V_w = 0. \qquad (11)$$

9/ These two homogeneity assumptions were also adopted by Mohring and Harwitz.

It is easier to understand equation (11) if it is rewritten as:

$$(N/w)\cdot V_N = -V_w. \tag{12}$$

The right-hand side of (12), $-V_w$, gives the time-cost saving due to additional capacity, since $V_w < 0$. This saving in time-costs from additional capacity can be translated to saving in time-costs due to a decrease in traffic. When V is homogeneous of degree 0, having one more unit of capacity is equivalent to having N/w less traffic. We therefore conclude that $(N/w)\cdot V_N$ gives the capacity-equivalent savings in time-costs due to a decrease in traffic.

21. The total revenues raised from the congestion charges, G^c, and the total revenue raised from the road damage charge, G^d, are as follows:

$$G^c = N\cdot(N\cdot V_N),$$
$$G^d = N\cdot(E\cdot M_{D/w}).$$

Meanwhile, the average road costs per trip borne by the highway authority will be referred to as the average road costs per trip ARC_N. Since the first term in (4) is borne privately, the last two terms represent the road costs borne by the highway agency. Hence we have:

$$\begin{aligned}
ARC_N &= (r\cdot w\cdot K + w\cdot M)/N && \text{since } K_0 \text{ is assumed to be zero} \\
&= (r\cdot K + M)\cdot(w/N) && \\
&= [(D/w)\cdot M_{D/w} - N\cdot V_w]\cdot(w/N) && \text{by (7)} \\
&= E\cdot M_{D/w} - w\cdot V_w && \text{since } D = N\cdot E \\
&= E\cdot M_{D/w} + N\cdot V_N && \text{by (11)} \\
&= MEC_N && \text{by (10).}
\end{aligned}$$

From the above calculation, we also readily see that:

$$G^c + G^d = N\cdot(N\cdot V_N + E\cdot M_{D/w}) = N\cdot(r\cdot w\cdot K + w\cdot M)/N = r\cdot w\cdot K + w\cdot M.$$

Hence we see that, if there are constant returns to scale in road construction and in road use, then the optimal road user charge, $G^c + G^d$, will cover the annualized capital costs of the road network and the total [variable] expenditures on periodic road maintenance. In spite of its familiar tone, this result is a little surprising: while all of the (total as well as average) road costs are borne by the highway agency, only part of the marginal external cost ($E\cdot M_{D/w}$) is borne by it. However, given that all of MEC_N is taxed as the unit tax, which becomes the average tax revenues, and that appropriate assumptions guarantee the equality of ARC_N and MEC_N, it then becomes clear that total tax revenues will exactly balance total road costs.

III. ASSUMPTIONS UNDERLYING OPTIMAL PRICING

22. The above pricing model is based on two important sets of assumptions. The first set deal with the nature of the road network and its usage (assumption I), the condition of the road pavement and the type of road maintenance regime adopted by the highway agency (assumption II), and the effect of pavement conditions on vehicle operating costs (VOCs) (assumption IV). These assumptions appear reasonable and are merely introduced to simplify the analysis. The second set relate to the way road maintenance costs are specified (assumption V), the construction cost function (assumption VI), the nature of the congestion cost function (assumption VII), and the relationship between congestion costs and adjustments to road capacity (assumption III). These assumptions are also introduced to simplify the analysis, but do so at the expense of making the model unrealistic. Furthermore, they cannot easily be avoided and have an important effect on cost recovery.

3.1 Acceptable Simplifying Assumptions

23. Assumption I is that the road network has a fixed length and there is a constant flow of traffic per km. Extending the road network therefore reduces the traffic flow per km, while growth in traffic increases it (hence partly offsetting the effect of extending the network). The optimum pricing model is therefore formulated in static, rather than dynamic terms. The prices calculated from the model only apply at a particular point in time and need to be recalculated each time the network is extended and/or there are changes in the volume of traffic. Although the model could be reformulated in a dynamic setting, this would complicate the model and hinder interpretation of the results (Newbery, 1987, p. 3). Provided the model is only used to estimate user charges for a particular point in time, and is periodically re-estimated to take account of changes in road lengths and traffic volumes, the first assumption is reasonable in the interests of simplification.

24. Assumption II deals with the strength and condition of the road pavement. It includes two elements: (i) the road network is taken to be made up of individual road sections with uniformly distributed ages; and (ii) the highway agency is assumed to operate a condition-responsive maintenance regime (i.e., road maintenance is carried out when each section of road reaches a pre-specified terminal degree of roughness). This means that the average roughness of the road pavement remains constant across the entire road network. This is a fairly strong assumption, since there are historical rhythms in the building of roads and significant parts of the road network usually become due for rehabilitation at the same time (Gakenheimer, 1989). Highway agencies are, furthermore, generally prevented from adopting a condition-responsive maintenance regime by external budgetary constraints. The average roughness of the road network can therefore vary quite widely. For example, between 1979 and 1984, average road roughness in Brazil increased by nearly one percent each year (see Table 1), while the average

roughness of paved roads in Ethiopia and Ghana decreased by 15 percent and 8 percent respectively between 1984 and 1988, and in Sudan and Nigeria increased by 3 percent and 2 percent respectively over the same time period (Harral and Faiz, 1988, Table A-2; Mason and Thriscutt, 1989, Table 3). At times the actual roughness of the road pavement will thus be higher than the long-term average, while at others it will be lower. This creates an awkward inconsistency. A sub-optimal road maintenance regime delivers perverse signals to users. When road maintenance is reduced, roughness increases and this increases VOCs: lower road quality thus costs road users more, while higher quality costs less. The assumption of constant average roughness is nevertheless unavoidable in the interests of simplifying the analysis.

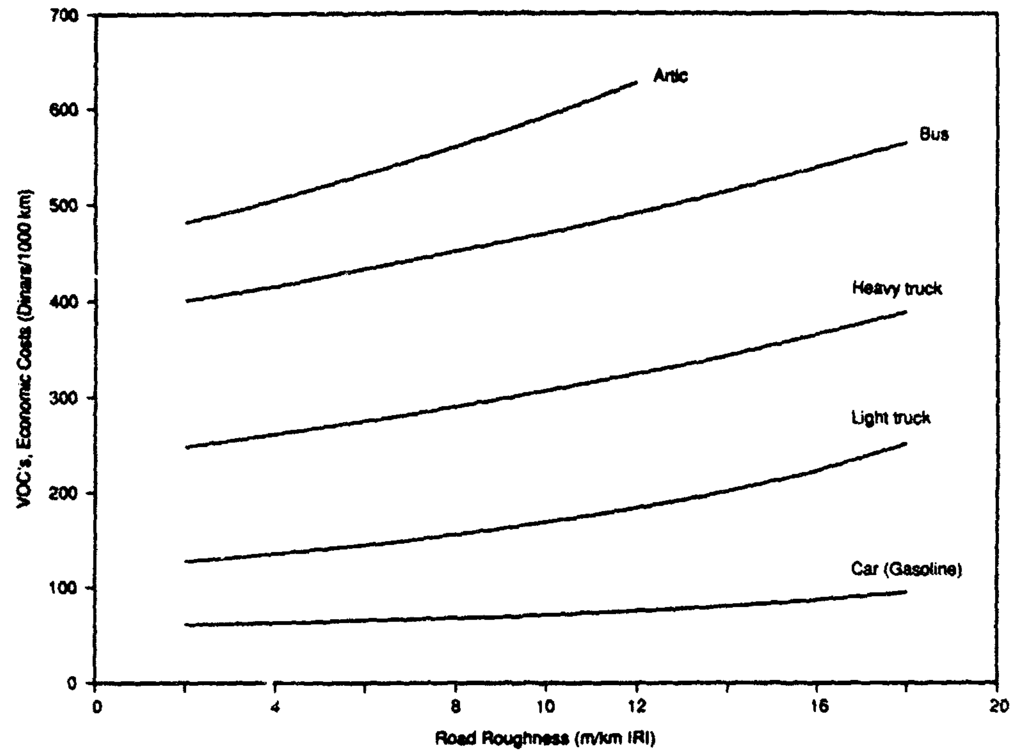
Table 1. Changing Condition of Brazil's Road Network (percent and weighted average)

Road Condition	1979 km	1979 percent	1984 km	1984 percent	Change 1979-1984 percent
Good	10,000	24	14,000	30	
Fair	23,000	58	19,000	42	
Poor	7,000	18	13,000	28	
		—		—	
Weighted Average					
weights (a)		156		163	4.5
weights (b)		135		141	3.8
		—		—	—

(a) Good = 1.0, Fair = 1.5, Poor = 2.5.
(b) Good = 1.0, Fair = 1.5, Poor = 2.0.

Note: The increase in the number of roads in good condition was caused by new construction. About 6,000 km of new paved roads were added to the network, while 2,000 km formerly in good condition declined to fair.
Source: (Harral and Faiz, 1988, Box 1-3)

25. Assumption IV assumes that vehicle operating costs are a linear function of the average roughness of the road pavement. This is a reasonable assumption. Although they are not strictly a linear function of the average roughness, they are nearly so and the discrepancy is of little practical importance. This is illustrated in Figure 1 for Tunisia. Since the figures are based on generic VOC figures, the relationship will hold in other countries as well.



Source: Paterson, 1985, Table 2.13.

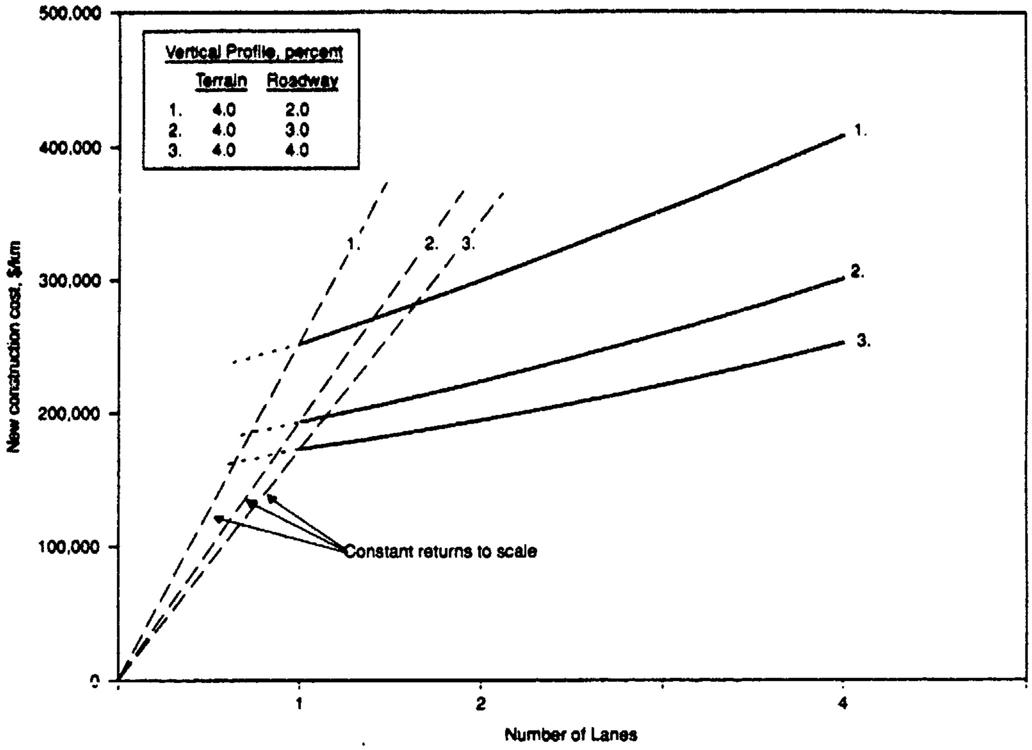
Figure 1: Relationship Between Vehicle Operating Costs in Tunisia and the Roughness of the Road Pavement

3.2 Unacceptable Simplifying Assumptions

26. Assumption V assumes that road maintenance costs consist exclusively of the variable costs of the periodic overlays (resurfacing) which are applied to the road pavement every 10 to 20 years. The fixed costs of this periodic maintenance, which account for between 20 percent and 65 percent of these costs, have been omitted.10/ These periodic expenditures are incurred at intervals greater than one year and consist of surface dressing and overlays for paved roads and re-graveling for un-paved roads. Note that, on an individual road, such expenditures would normally be treated as fixed costs. However, since between one-tenth and one-twentieth of the road network is resurfaced each year, these expenditures can be treated like

10/ The proportion of the overlay costs which are fixed are specified in terms of climatic conditions as follows: dry non-freeze = 20%, dry freeze = 45%, wet non-freeze = 30%, and wet freeze = 65% (Newbery, et al, 1988, p. 84).

marginal costs. The model also ignores all routine maintenance costs, which generally account for at least half total road maintenance expenditures.11/ Routine maintenance amounts to between $1,000 and $3,000 per km for paved roads and between $500 and $1,500 per km for unpaved roads, depending on the country and volume of traffic. Up to 70 percent of these costs are typically fixed, the remainder being attributable to the passage of vehicles (patching) and the incidence of heavy vehicles (e.g., shoulder maintenance).



Note: Shoulders are all 1.5 m wide, pavements are 3.5, 7.0 and 2 x 7.0 m wide and the 2-lane road has a 5 m central reservation.
Source: Archando-Callao, 1990.

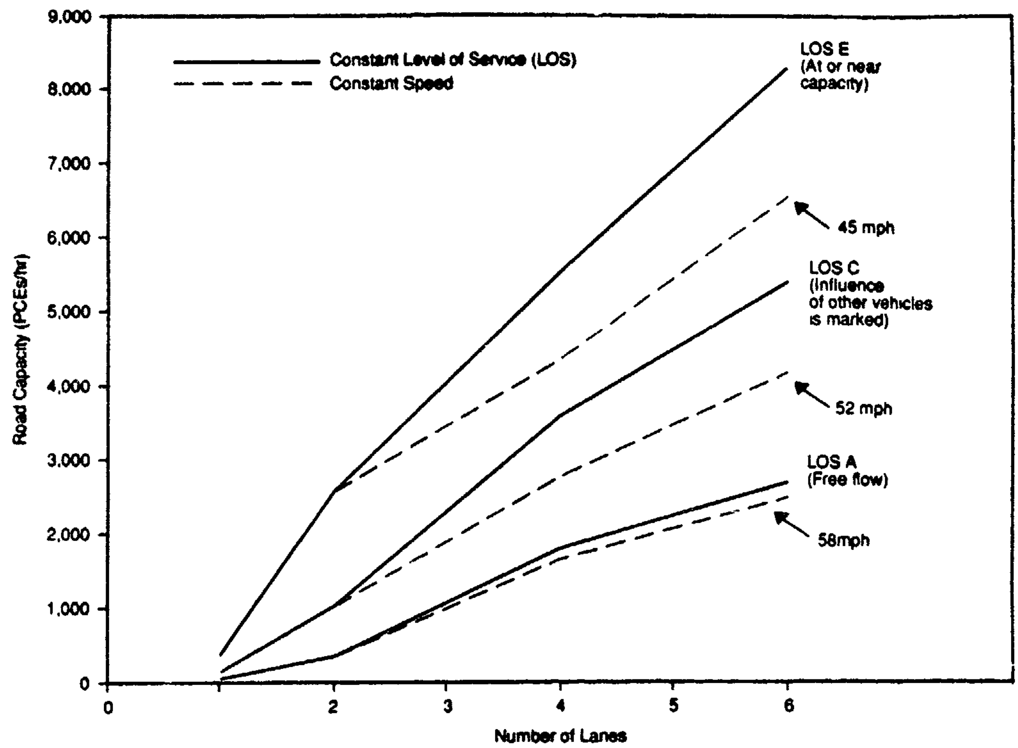
Figure 2: Economies of Scale in Constructing Inter-Urban Roads

11/ In Arizona, U.S.A., with over 100,000 km of roads and streets, fixed costs accounted for about 65 per cent of annual road maintenance expenditures in 1989 (Arizona Department of Transportation, 1989).

27. Assumption VI deals with the costs of road construction. These are specified as, $K_0 + wK(S)$, where K_0 is a constant term reflecting the incidence of economies of scale in road construction. To simplify the analysis, it is assumed there are constant returns to scale in road construction so that K_0 is equal to zero. The author recognizes this assumption is unrealistic, since there are substantial economies of scale in constructing non-urban roads up to four lanes. This is illustrated in figure 2; it is based on empirical data from several countries and is equally applicable to Tunisia. In urban areas, on the other hand, rising land values increases the average cost function and this decreases the effect of increasing returns to scale. The two effects may therefore cancel out in urban areas and the assumption of constant returns to scale may be reasonable (Newbery, 1987, p. 9; Small et al, 1989, pp. 101-102). However, urban roads in developing countries generally account for less than 20 percent of the paved road network and perhaps 10 percent of the classified network (the figures for Tunisia are 19.1 percent and 10.5 percent respectively) (Paterson, 1985) and even in developed countries they still only account for between 18 percent (USA) and 47 percent (W. Germany) of the total road network (Annual Bulletin, 1986, Table 11). When applied to an entire road network, the assumption of constant returns to scale in road construction is therefore too strong.

28. Assumption VII assumes that the time costs associated with traffic congestion are homogeneous of degree zero in N and w. In other words, if the volume of traffic doubles and the number of lanes is doubled, vehicle speeds will remain the same. This is unfortunately untrue. Regardless of whether road capacity is compared on the basis of constant speeds, or constant levels of service (LOS), which describe how the interactions between vehicles affect road speeds and capacity, it is clearly not directly related to the number of lanes. The relationship between these two quantities is illustrated in Figure 3. It is based on generic data and therefore applies to all countries, including Tunisia. The continuous lines refer to constant speeds and the broken lines to constant levels of service. On an uncongested inter-urban road (average speed 58 mph, or LOS = A), the capacity of a four-lane road is 4.6 to 5.0 times that of a two-lane road and over 30 times that of a single-lane road. With moderate congestion (average speed 52 mph, or LOS = C), the ratio falls to 2.7 to 3.5 and 18 to 23 respectively, and only approaches 2.0 on roads with two or more lanes experiencing serious congestion (average speed 45 mph, or LOS = E), or on roads with more than four lanes. Since a relatively small proportion of the road network in most countries will be seriously congested, or exceed four-lanes (in Tunisia there are no roads over four lanes) (Paterson, 1985), the assumption that time costs are homogeneous of degree zero is too strong.

29. Finally, assumption III assumes that road capacity can be smoothly adjusted to traffic. In other words, roads are assumed to be infinitely divisible and are always operating at their optimal capacity. This is an important weakness. Road investments are inherently lumpy, at least at the network level, and although there is scope for increasing road capacity at the margin, particularly in urban areas (Starkie, 1982), the main increments in capacity — from one lane to two and from two to four — can only be added in indivisible lumps. This means that much of the road network will be operating well below its optimal capacity and congestion



Source: Two and 4-lane road, Transportation Research Board, 1985; single lane roads, Hoban, 1987, Table 11, figures for India.

Figure 3: Relationship Between Road Capacity and Number of Lanes

costs will be less than the marginal costs of adding additional road capacity. This creates special problems in countries with low traffic densities. The lumpiness of investments means there is little traffic congestion — a common feature of the road systems in most developing countries — and congestion costs are close to zero. There are only limited sections of road where the network is operating at capacity, unless investment is sub-optimal (or there are physical and/or environmental constraints restricting capacity) which allows congestion to build up beyond the point where further investment would be economically justified.

IV. RELAXING UNACCEPTABLE ASSUMPTIONS AND THE CASE OF TUNISIA

30. The following section examines what happens to cost recovery when the unacceptable limiting assumptions discussed in section 3 are relaxed. In each case relaxation of the assumption seems to bring in scale economies which leads to the attendant deficits when prices are set equal to marginal costs. The section then applies the optimal pricing model to a case study in Tunisia to show, in quantitative terms, the importance of these assumptions for cost recovery. It is important to point out, however, that the case study only considers the classified road network in Tunisia (17,000 km) and roads in urban agglomerations (1,800 km). The remaining 14,000 km of unclassified roads have been omitted (Paterson, 1985).

4.1 Relaxing Unacceptable Assumptions

31. Let us see how the balanced budget conclusion in the optimal pricing model is affected if the unacceptable assumptions are relaxed. Specifically, we investigate the following cases: (A) the constant K_0 in the road construction function is not zero; (B) there is a positive constant M_0, denoting fixed maintenance cost, in the total cost function;12/ (C) the time cost function V is not homogeneous of degree zero (in particular, we consider the case where an additional lane can handle more traffic than the previous lane); and (D) the road capacity cannot be smoothly adjusted to traffic, so that the network is not in an optimal equilibrium condition.

32. Consider case (A) and assume that the constant K_0 in the road construction function is not zero. If optimal pricing is still adopted, the minimization conditions (7) and (8) still hold since an additional constant in the TC function does not affect any derivative at all, and a tax of MEC_N is imposed. Hence ARC_N is still equal to MEC_N. Let us refer to the average road costs of the trip in the previous model and in this relaxed case as ARC_N and ARC'_N respectively. Then we have $ARC'_N = ARC_N + r \cdot K_0/N$. But this implies that:

$$ARC'_N = MEC_N + r \cdot K_0/N > MEC_N,$$

and the total revenue raised by G^c and G^d will then be less than the road costs borne by the highway agency.13/

12/ It would be fairly simple in the Newbery model to include the routine maintenance costs which vary with the volume of traffic, N, as well as D, the number of heavy axles.

13/ Since cases A and B involve adding a constant to the objective function in Newbery's model, the same second-order sufficient conditions are required to hold. In case C, we assume the existence of second-order sufficient conditions as well.

33. It is clear that the inclusion of a constant, M_0, to denote the fixed maintenance cost in the TC function has the same effect as the inclusion of a non-zero constant K_0 in the TC function. Therefore, the average external cost of a trip will exceed the marginal external cost of the trip in case (B) as well.

34. Next, we consider the case where V is no longer homogeneous of degree 0, and additional capacity is better than average capacity.14/ As mentioned earlier, capacity in this model is indirectly presented: it is not given by the volume of traffic, but is given by the saving in time-cost when capacity is increased. Hence, the additional capacity is represented by $-V_w$ units of cost saved (recall that as w increases, users time-cost decreases and V_w is negative). Given that there are w units of capacity and the total volume of traffic is N, the average volume of traffic per unit of capacity is N/w. The marginal impact on time-cost of an additional trip is V_N, or, to put it differently, one less trip saves V_N units of time-cost. Hence N/w less trips saves a total of $(N/w)\cdot V_N$ units of cost. Since adding an existing unit of capacity is equivalent to having N/w less traffic, the average capacity is given by the total cost saved: $(N/w)\cdot V_N$.

35. In case (C), since additional capacity is better than existing capacity, we have:

$$-V_w > (N/w)\cdot V_N.$$

As before, relaxing the homogeneity assumption of V does not affect the minimization conditions (7) and (8) and the marginal external cost of the traffic, MEC_N, is still given by (10). However, in this case, as in the above two cases, the average road cost per trip exceeds the marginal external cost of a trip:

$$\begin{aligned} ARC_N &= (r\cdot w\cdot K + w\cdot M)/N = E\cdot M_{D/w} - w\cdot V_w && \text{by (7)} \\ &> E\cdot M_{D/w} + N\cdot V_N && \\ &= MEC_N. && \text{by (10).} \end{aligned}$$

Again, the cost recovery proposition is lost and the total revenue raised by G^c and G^d will be less than the road costs borne by the highway agency.

36. Case D is not really an assumption, but follows as a consequence of using differential calculus. The analysis is all done in terms of a single km of road — carrying a constant flow of traffic — which can be smoothly adjusted to traffic, i.e. the number of lanes can be smoothly adjusted to ensure that the costs of congestion are just equal to the costs of adding a marginal increment in road capacity. The one km section of road is then generalized

14/ Mathematically, we assume that V is homogeneous of a negative degree. The current paragraph presents the intuition to explain why this should be the case. By Euler's equation, if V(w,N) is homogeneous of 0 degree $k < 0$, $w\cdot V_w + N\cdot V_N = k < 0$. This is the first inequality in the next paragraph.

and applied to the road network as a whole. This formulation cannot handle spatial and temporal variations in traffic, changes in travel demand and the obvious indivisibilities associated with expanding capacity. Since these factors are not assumptions, but follow from the nature of the mathematics, they cannot be relaxed. Furthermore, since indivisibilities are generally recognized to be a source of scale economies, they automatically cause deficits when prices are set equal to marginal costs.

4.2 The Case of Tunisia

37. The impact of the above assumptions are illustrated in Table 2. The table shows that actual expenditures on highways in Tunisia amounted to $91.62 million in 1982, including the shortfall of regular routine maintenance and financing charges. This does not, however, necessarily represent the economically efficient costs of delivering road services (i.e. these costs may be inflated by allocative inefficiencies on the input side). This will not be dealt with in the present paper, even though it is known that production inefficiencies can be important for pricing and cost recovery policies (Kranton, 1990). Instead, the paper will focus on the pricing of road services to optimize allocative efficiency on the demand side.

38. Table 2 shows several discrepancies between the costs incurred and the revenues generated by optimal pricing. The variable costs of resurfacing (item (iv), column 2), are less than half the costs actually incurred on road maintenance (item (v), column 1), even when the shortfall of routine maintenance (item (iii), column 1) is excluded. When capital and financing costs are included, the optimum pricing model only covers just over half the total costs. User charges set on the basis of the above optimal pricing model will therefore leave a large block of expenditures unfunded.

Table 2. Actual Costs and Those Covered by Optimal Pricing Model: Tunisia 1982 (Dollar Million at 1982 Prices)

	Item	*Actual Costs Incurred (1)*	*Revs Generated by Optimal Pricing Model (2)*
Recurrent Expenditures:			
(i)	Administration	2.44	-
(ii)	Routine Maintenance	22.48	-
(iii)	Shortfall of Routine Maintenance (a)	[illegible].62	-
(iv)	Resurfacing:		
	fixed (b)	5.17	-
	variable	20.68	20.68
(v)	Sub-Total	56.39	20.68
Capital Expenditures: (c)			
(vi)	Extension/Improvement	9.80	-
(vii)	Expansion of Capacity	19.60	-
(viii)	Annualized Construction Cost (d)		
	non-urban roads	-	13.68
	urban roads	-	20.00
(ix)	Fixed Resurfacing Cost (e)		
	non-urban roads	-	0.20
	urban roads	-	0.30
Financing Charges: (f)			
(x)	Debt Service/Repayment	5.83	-
	Sub-Total	35.23	34.18
	Grand Total	91.62	54.86
	Unfunded Road Expenditure	-	36.76

Notes:

(a) Since road conditions were generally deteriorating, it is estimated that allocations for routine maintenance were about 20 percent lower than needed to maintain the road network in a stable long-term condition.

(b) These represent weather related resurfacing costs which are unrelated to traffic. They comprise about 20 percent of total resurfacing costs in "dry non-freeze" countries like Tunisia.

(c) Assuming one-third of capital expenditures are new construction and the remainder are to expand capacity. Real capital expenditure between 1976 and 1982 was fairly stable and fluctuated within about 20 percent of the mean expenditure for the period.

(d) See Annex 1 for derivation of these figures.

(e) The additional fixed resurfacing costs associated with expanding capacity. They are calculated as 1.5 percent of initial costs.

(f) This item refers to World Bank loans only. It appears elsewhere in the government's accounts and is usually omitted from financial statements of road revenues and expenditures.

Source: World Bank, 1987 (b); Newbery et al, Table 21, 1988.

V. FINANCING REMAINING EXPENDITURES

39. Figures 2 and 3 showed that there are substantial economies of scale in road construction and in road use. Road maintenance costs also contain a number of important fixed costs. Furthermore, since roads cannot be smoothly adjusted to traffic, marginal costs for the entire road network will be significantly lower than average costs, unless capacity is artificially constrained by environmental or other constraints. User charges based on the above optimal pricing model will therefore result in substantial financial deficits. This was shown in the Tunisian example presented in Table 2. The question which then arises is, how should this deficit be financed? The only feasible options on a network basis are by raising revenues from users, raising additional general tax revenues, or by taxing beneficiaries. Taxing beneficiaries, i.e. imposing taxes on the property which benefits from provision of roads, are only suitable for roads which primarily provide access to property like residential streets and rural access roads. For other roads — those which primarily provide services to traffic — the alternatives are user charges or general tax revenues. This paper concentrates on these roads and does not examine the option of taxing beneficiaries.15/ The other option — cutting back expenditures on maintenance and investment to reduce the deficit — is not economically efficient, since it increases user costs more than it reduces road expenditures (Harral and Faiz, 1988).

40. The economic consequences of the above choices can be examined in terms of Figure 4. In this figure, demand for travel is shown by **D**, while costs — including VOCs and marginal external road costs — are shown by **ASC** and **MSC**. Under average cost pricing, the volume of travel is **N** at price **P**. Likewise, under marginal cost pricing, the volume of travel would be **N'** at price **P'**. The move from point **A**, where roads are priced at average costs, to point **B**, where they are priced at marginal costs, leads to a net increase in total surplus equal to the area of triangle **ABC**. However, the move from **A** to **B** also results in a deficit equal to the area of **EBP'F**. The welfare comparison is thus between the welfare gain, **ABC**, attributable to the move from average to marginal cost pricing, less the welfare costs of the taxation required to finance the deficit. Let **m** denote the costs of taxation (deadweight and administrative costs) expressed as a constant percentage of the tax revenues. Then it immediately follows that the welfare costs of financing the required deficit is just **m·EBP'F**. Provided the administrative costs of mobilizing these tax revenues are similar to those associated with road taxation16/, the benefits of marginal cost pricing will exceed the costs only if **m·EBP'F < ABC**, or **m < ABC/EBP'F**.

15/ The alternative of financing the deficits through domestic and/or international borrowing, merely defers payment, since the loans still need to be serviced and repaid.

16/ The administrative costs should be similar, since many of the tax instruments — import duties, sales and excise taxes — are used to collect both road user taxes and general revenues.

41. Since the non-marginal costs (the difference between **MSC** and **ASC**) are fixed, the rectangle **EBP'F, EB.N'**, is also equal to **AC.N**. The above inequality can thus be written as :

$$\mathbf{m} < (1/2)\cdot AC\cdot(N'-N)/(AC\cdot N)$$

or $$\mathbf{m} < (1/2)(N'-N)/N$$

or $$\mathbf{m} < (1/2)\Delta N/N$$

where Δ denotes a finite charge: $\Delta N = (N'-N)$, $\Delta P = (P-P')$. Since the point elasticity **e** evaluated at point **A** is defined to be $(\Delta N/N)/(\Delta P/P)$, it follows that:

$$\mathbf{m} < -\ (1/2)e\ \Delta P/P$$

The right-hand side of this inequality has been plotted in Figure 5 as a function of the proportional fall in price, $\Delta P/P$, given the all-day price elasticities of demand for automobiles and buses, and the aggregate price elasticity of demand for trucks (from Annex 2).

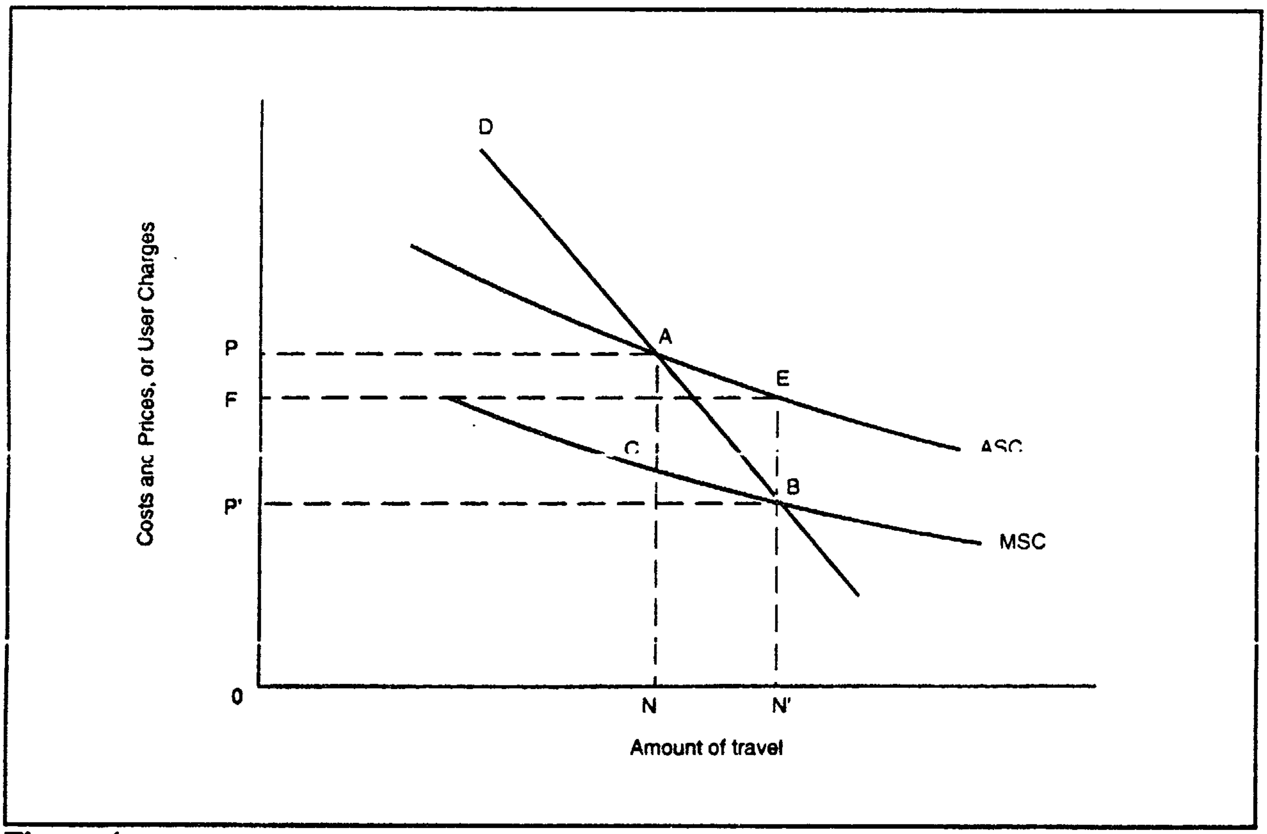


Figure 4: **Effect of Marginal and Average Cost Pricing on Total Surplus**

42. Figure 5 can now be used to examine whether in Tunisia it is more economically efficient to mobilize the required revenues from road users, or by raising additional general tax

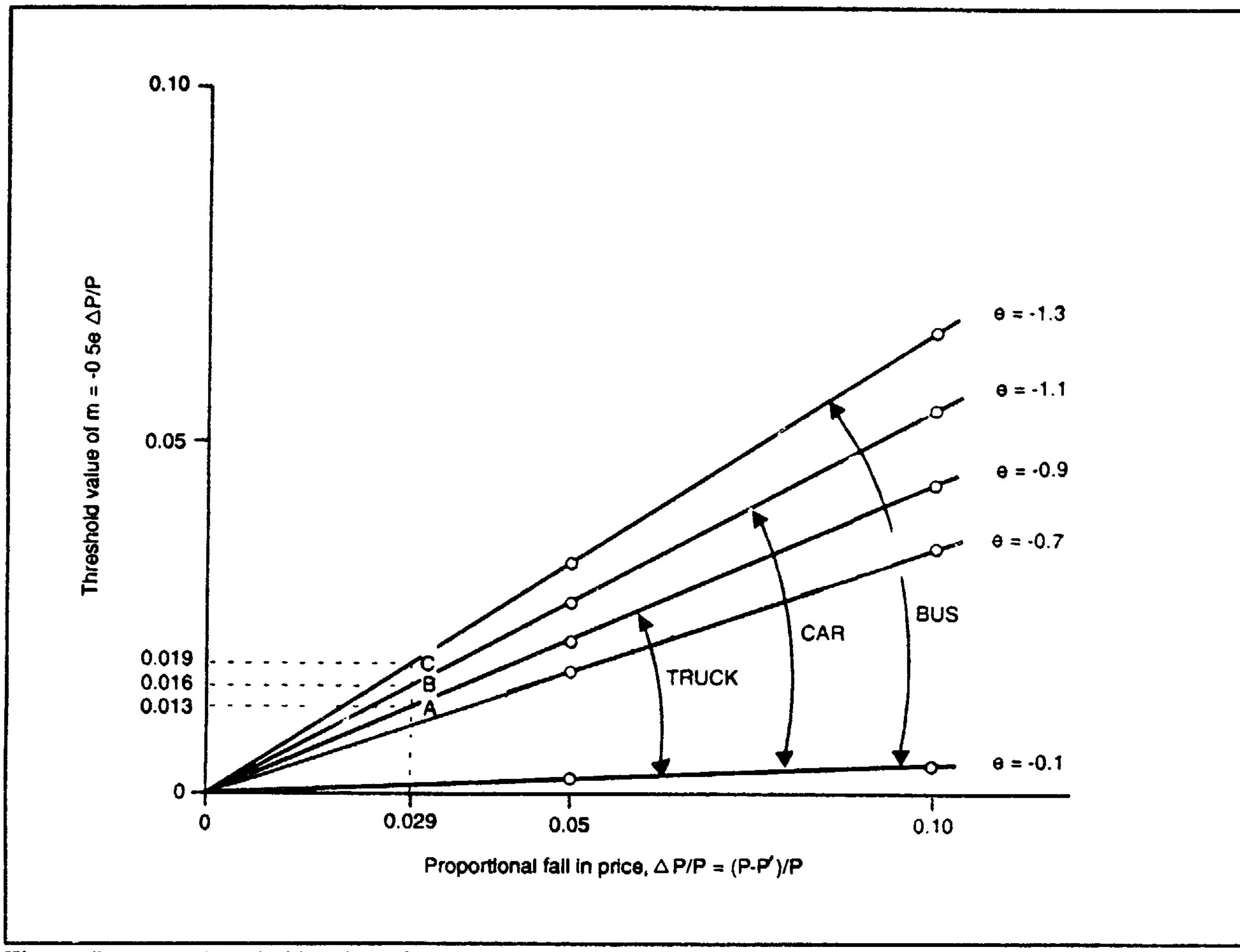


Figure 5: **Threshold Value of the Marginal Cost of Public Funds as a Function of the Proportional Fall in Price, Given Different Elasticities of Demand.**

revenues. Recall that the unfunded road expenditures shown in Table 2 amount to about \$37 million (costs of about \$92 million, less revenues from optimal user charges of about \$55 million). The marginal external costs of road use per veh km (for each class of vehicle) are set out in Table 3, column 15. If user charges are set equal to these marginal external costs, they will generate total revenues of about \$55 million. Column 17 shows the size of the <u>ad valorem</u> mark-up over the marginal external costs of car use (optimal user charges, plus VOCs) needed to generate the required additional \$37 million to cover the unfunded road expenditures shown in Table 2. It does so by charging average costs, i.e., by raising the marginal costs of car use (shown in column 16) by the amounts shown in column 17. The average mark-up comes to

Table 3. Optimal User Charges and Ad Valorem Mark-up Needed to Cover Unfunded Road Expenditures: Tunisia, 1982

(c/veh km and $ million)

Vehicle Type	Vehicle Characteristics: VOCs economic (c/km) (1)	PCEs I-U (2)	PCEs Urban (3)	ESAs (4)	Usage of Road Network: Veh km (mill) I-U (5)	Veh km (mill) Urban (6)	Veh km (mill) Total (7)	PCE km (mill) I-U (8)	PCE km (mill) Urban (9)	PCE km (mill) Total (10)	ESA km (mill) (11)	Optimal User Charges (c/ veh km): Road Damage Cost (12)	Congestion Cost I-U (13)	Congestion Cost Urban (14)	Total (15)	Optimal User Charges + VOCs (c/veh km) (16)	Ad Valorem Mark-up over Costs (c/veh km) (17)
Car Gasoline	8.79	1.00	1.00	0.0001	1404	880	2284	1,404	880	2,284	0.2	0.00	0.16	0.23	0.39	9.18	0.26
Car Diesel	6.44	1.00	1.00	0.0001	464	291	755	464	291	755	0.1	0.00	0.16	0.23	0.39	6.83	0.20
Utility Vehicle	12.44	1.00	1.00	0.0080	1721	851	2572	1,721	851	2,572	20.6	0 01	0.16	0.23	0.40	12.84	0.37
Light Truck	30.37	1.50	1.50	0.0920	441	218	659	662	327	989	60.6	0.09	0.25	0.34	0.68	31.05	0.89
Medium Truck	32.37	1.70	2.00	0.5800	161	16	177	274	32	306	102.7	0.59	0.28	0.45	1.32	33.69	0.97
Hvy Single Truck	39.13	2.00	2.50	2.6000	204	20	224	408	50	458	582.4	2.65	0.33	0.56	3.55	42.68	1.23
Hvy Tandem Truck	39.13	2.00	3.00	5.3800	12	1	13	24	3	27	69.9	5.49	0.33	0 68	6.50	45.63	1.31
Articulated Truck	75.78	2.00	3.00	6.8000	133	7	140	266	21	287	952.0	6.94	0.33	0.68	7.94	83.72	2.41
Bus	62.38	2.00	3.00	0.4900	125	63	188	250	189	439	92.1	0.50	0.33	0.68	1.51	63.89	1.84
Special Vehicle	62.38	1.50	1.50	0.4900	220	78	298	330	117	447	146.0	0.50	0.25	0.34	1.08	63.46	1.83
Totals					4885	2425	7310	5,802	2761	8,563	2026.6						
								Total User Costs/Revenues				20 68	13.88	20.30	54.86		36.76

Notes: Heavy single-axle trucks have the same VOCs as heavy tandem-axle trucks, and special vehicles have the same VOCs as buses.

Source: (Newbery, et al, 1988)

about 2.9 percent and the final user charge would then consist of column 15 plus column 17. When the percentage mark-up, 2.9 percent, is applied to Figure 5, it intersects the highest relevant elasticity curves at points **A** (truck), **B** (car) and **C** (bus) resulting in threshold values of **m**, representing the costs of mobilizing additional general tax revenues, of 1.3, 1.6, and 1.9 percent respectively. In other words, if the value of **m** is less than 1.9 percent it will be more economically efficient to raise the required revenues through general taxation; while if it is greater than 1.9 percent, it is better to do so by collecting the required revenues from road users. Even if the percentage mark-up increases to 10 percent, the value of **m** still has to be less than 6.5 percent before it is more economically efficient to raise the required revenues through general taxation.

43. Recent work has shown, however, that the deadweight losses caused by general taxation are high. Using a general equilibrium model, it has been shown that the welfare loss from a one percent increase in all existing (distortionary) tax rates in the USA is between 17 and 56 cents per dollar of extra revenues raised (Ballard et al, 1985). Other estimates for the USA (Browning, 1986), Canada and Sweden are similar, while in the UK a more limited partial equilibrium approach suggests that the economic costs of raising public revenues lie in the range 11 percent to 21 percent for local property and income taxes respectively (Dodgson and Topham, 1987). In developing countries like Tunisia, with narrow tax bases and weak tax administration, the costs of mobilizing additional tax revenues are likely to be even higher. This means that **m** is likely to be well above 2.9 percent in Tunisia and is also likely to be above this figure in other developing countries.

44. The above analysis has shown that, provided the administrative costs of road user taxes are similar to general revenue taxes, the welfare costs of marginal cost pricing plus general taxation are likely to be higher than the welfare costs of average cost pricing in most developing countries. It follows that a pricing system which uses optimal departures from marginal cost pricing to finance the deficit **EBP'F** (where some services may be priced below average costs and others above it) will be even more attractive in welfare terms. This leads to the overall conclusion that, given the generally high costs of general taxation, welfare will nearly always be greater if the financial deficits associated with marginal cost pricing are financed using optimal mark-ups over marginal costs.

VI. EFFICIENT COST RECOVERY

45. The above analysis has established two important conclusions. First, if the user charges for an entire road network are based on short-run marginal costs (variable road maintenance costs, plus the costs of traffic congestion), they will nearly always generate insufficient revenues to cover total costs. This has been demonstrated for Tunisia — and will generally hold for all road networks with low traffic densities — unless road capacity is artificially constrained and congestion is allowed to increase well beyond the point where benefit/cost criteria would recommend expanding capacity to reduce congestion. Second, the high costs of mobilizing public revenues, suggests that the additional revenues needed to balance the road budget should be collected from road users, preferably by using an optimal mark-up over marginal costs. These conclusions also raise three further questions: (i) while it is generally accepted that marginal costs should be regarded as the floor below which user charges should never fall, is it necessary to stop at short-run marginal costs when a significant number of the remaining costs are avoidable, but not necessarily marginal? (ii) how does one calculate the optimal departures from marginal costs needed to finance the unfunded road expenditures? and (iii) is road congestion pervasive and is it feasible to charge for it.

6.1 Variable and Common Costs

46. All the costs in Table 2, column 1, other than the financing costs, are — at least in principle — avoidable.17/ They are not all marginal, but can be avoided over a reasonable period of time. Indeed, there are three broad levels of avoidability, costs which: (i) are variable and are incurred on behalf of identifiable users (these are the variable costs of the road agency and include the road damage costs from the optimum pricing model); (ii) can be avoided over a short period of time and are incurred as common costs on behalf of an identifiable group of users, but not of individual members of the group (e.g. heavy vehicles); and (iii) are avoidable, but are common to all users (they can only be avoided by closing the entire road network). In practice, road users cannot be excluded from using the road network. The concept of avoidability nevertheless provides a pragmatic way of attributing ex post expenditures to specific user groups. In the rest of this paper these three groups of costs will be referred to as variable costs, grouped common costs and collective common costs.

47. Table 4 has divided the costs set out in Table 2, column 1, into these three categories and shows that they comprise 29, 26 and 45 percent respectively of total road expenditures in Tunisia. The first category, column 1, are caused by the passage of vehicles

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17/ The financing costs can only be avoided by defaulting, or rescheduling the loans.

over the road pavement (variable administrative and routine maintenance costs) and by the passage of heavy axles (variable resurfacing costs). Being marginal, such costs should clearly be recovered from users: the former in terms of veh km (since there is no other straight-forward way of attributing them to users), the latter according to ESA km (to reflect the damage done to the road pavement by the passage of heavy axles).

Table 4. Analysis of Costs in Terms of Their Avoidability: Tunisia, 1982 (a) (Dollar, million)

Item	Immediately Avoidable Costs (Marginal) (1)	*Common to Specific Groups of Users* Heavy Vehicles (2)	Urban Roads (3)	Rural Roads (4)	Common to all Users (Fixed) (5)	Total User Costs (6)
Administration (b)	0.49	-	-	-	1.95	2.44
Routine Maintenance (c)	5.62	2.81	-	-	19.68	28.11
Resurfacing (d)	20.68	-	-	-	5.17	25.85
Extensions/Improvements (e)	-	4.42	5.55	11.10	8.33	29.40
Financing Charges (f)	-	-	-	-	5.83	5.83
Total	26.79	7.23	5.55	11.10	40.96	91.63
Percent of Grand Total	29.20	-	26.10	-	44.70	100.0

Notes: (a) Including shortfall of regular road maintenance.
(b) Fixed costs include all expenditures on buildings and 70 percent of salaries.
(c) 70 percent of these costs are fixed and 10 percent are attributable to heavy vehicles.
(d) In dry non-freeze conditions, 20 percent of resurfacing costs are attributable to environmental factors.
(e) Assuming one-third is new construction and the remainder is to expand capacity (of this, one-third is in urban areas and two-thirds in rural areas) and that 15 percent of these costs are incurred to ensure roads are strong enough to carry heavy vehicles.
(f) These costs can only be avoided by defaulting, or cancelling the loans.

48. There are two possible ways of dealing with the second category of costs. The first is to simply treat them in the same way as collective common costs and charge them against all users. This has some attractions on grounds of simplicity and economic efficiency. The second way is to charge them against each group of common users. This is more equitable and may hence be more politically acceptable. Each of the grouped common costs can, at least in principle, be avoided by withdrawing service from that specific user group: either heavy vehicles, urban road users, or rural road users. To justify serving them, each group should be willing to pay for the costs they incur: heavy vehicles again in terms of ESA km and urban and rural road users in terms of passenger car equivalent (PCE) kilometers (which measures the road space they occupy).18/ Finally, the collective common costs should be recovered from all users in a way which minimizes loss of consumer surplus.

6.2 Recovering Collective Common Costs

49. The collective common costs shown in Table 4, column 5, are incurred on behalf of several groups of common users and the aim is to define a mark-up over base costs (VOCs and variable and grouped common costs) which: (i) generates sufficient revenues to cover all collective common costs; while (ii) minimizing the consequent loss of consumer surplus. This is similar to the classical tax problem in which the overall excess burden of the tax is minimized by equalizing the marginal excess burden of the last dollar of tax revenues raised from each commodity (Ramsey, 1927; Rosen, 1988). In the case of roads, this translates into minimizing the relative loss of consumer surplus per dollar of collective common costs covered by each user group. This is illustrated in Figure 6. In this figure **D** represents the compensated demand curve for one particular type of traffic. The curve **BC** refers to base costs and represents VOCs and the variable and grouped common costs set out in Table 4, columns (1) to (4). Without any mark-up, demand would be in equilibrium at point **B**, with output **N** at price **P**. The amount $\mathbf{T \cdot P_i}$, the ad valorem mark-up over the base costs, represents the contribution (per veh km) which this type of traffic makes towards covering collective common costs. The deadweight loss per dollar of revenue raised through the increased user charge, S, is equal to the triangular deadweight loss area **ABC** divided by the contribution to collective common costs, **P"CAP'**. In other words:

$$\mathbf{S = 1/2 \cdot AC \cdot (N - N')/AC \cdot N'}$$
$$\mathbf{= 1/2 \cdot \Delta N/N'}$$

where $\mathbf{\Delta N = (N - N')}$.

18/ PCEs measure the impact which vehicles have on the speed, and hence the cost, of other vehicles. They vary by type of road, terrain and condition of traffic.

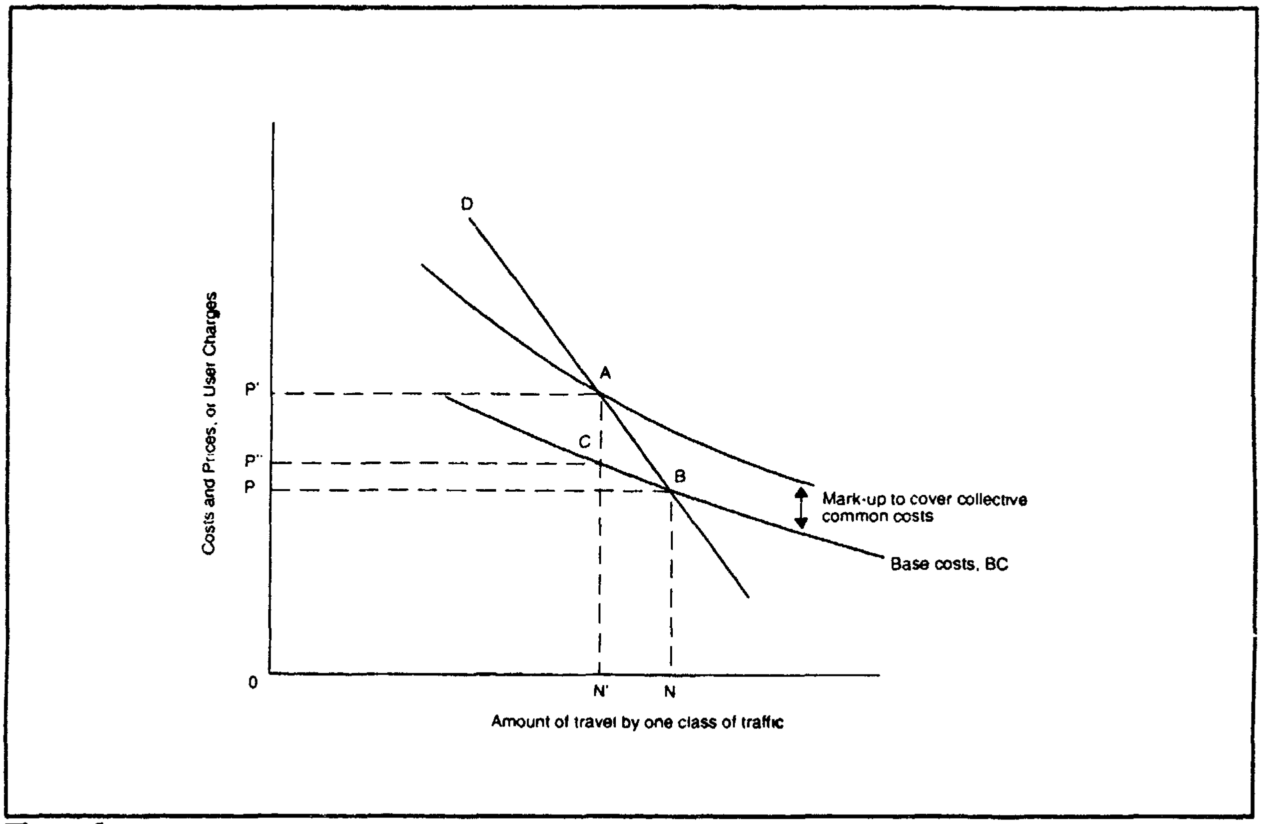

Figure 6: Loss of Consumer Surplus Associated with Covering Collective Common Costs

50. The own-price elasticity of demand at point **A**, e, is equal to **(ΔN/N')·(P'/ΔP)** and the elasticity of supply at point **A** is equal to **(ΔN/N')·(P"/ΔP')**, where **ΔN = (N-N')**, **ΔP = (P'-P)** and **ΔP' = (P"-P)**. Provided the cross-price elasticities of demand between the different user groups are relatively small, they can be ignored. 19/ Likewise, since the proportion of the budget allocated for spending on roads is small, the uncompensated demand elasticities (Annex 2) can be taken as a reasonable approximation of the compensated demand elasticities. The price elasticities of demand and supply, and the ad valorem mark-up, can then be used to calculate the deadweight loss, S, as follows:

$$1/e = N'\Delta P/\Delta N P', \quad ; \quad 1/s = N'\Delta P'/\Delta N P''$$
$$1/g = 1/e - 1/s = N'/\Delta N\ (\Delta P \cdot P'' - \Delta P' \cdot P')/(P' \cdot P'')$$

19/ **They are effectively zero for passenger versus freight transport, are low for public transport versus car (Baum and Kentner, p. 19, 1980) and even lower for car versus public transport. They are more significant when there are competing public transport modes (e.g., mini-bus versus bus). In such cases the price elasticity needs to be adjusted by subtracting the relevant cross-price elasticity (Taplin and Waters, 1985).**

Substituting for **ΔP** and **ΔP′** and simplifying:

$$1/g = (N'/\Delta P)\cdot P\cdot(P'-P'')/(P'\cdot P'')$$
$$\text{or } 1/g = (N'/\Delta N)\cdot P\cdot T\cdot P'/P'\cdot P'' = (N'/\Delta N)\cdot T\cdot P/P''$$
$$\text{or } \Delta N/N' = g\cdot T\cdot P/P''$$

where **T**, the <u>ad valorem</u> mark-up = **(P′-P″)/P′**.

Substituting this in the expression for the area **S** gives:

$$S = -1/2\cdot g\cdot T\cdot P/P''$$

51. Since there are several types of traffic, the overall loss of welfare is minimized by equalizing S across all user groups:

$$S = g_1T_1P_1/P_2'' = g_2T_2P_2/P_2'' = \ldots = g_nT_nP_n/P_n''$$

This is the so-called inverse elasticity rule (the term **g** being the inverse elasticity). The process of equalizing **S** across the different user groups is illustrated in Figure 7. With a constant elasticity demand curve, the lines representing car, bus and truck are straight lines; otherwise they are curves.

52. The revenue generated by the above mark-ups is calculated by multiplying each mark-up by the appropriate values of **P′** and **N′**, corresponding to that particular type of traffic. In other words:

$$\text{Revenue} = T_1P'_1N'_1 + T_2P'_2N'_2 + \ldots + T_nP'_nN'_n.$$

The appropriate value of S needed to generate the revenues required to cover common costs, can either be solved by trial-and-error, or by plotting a graph of total revenue as a function of S and taking the point where it intersects the horizontal total cost line.

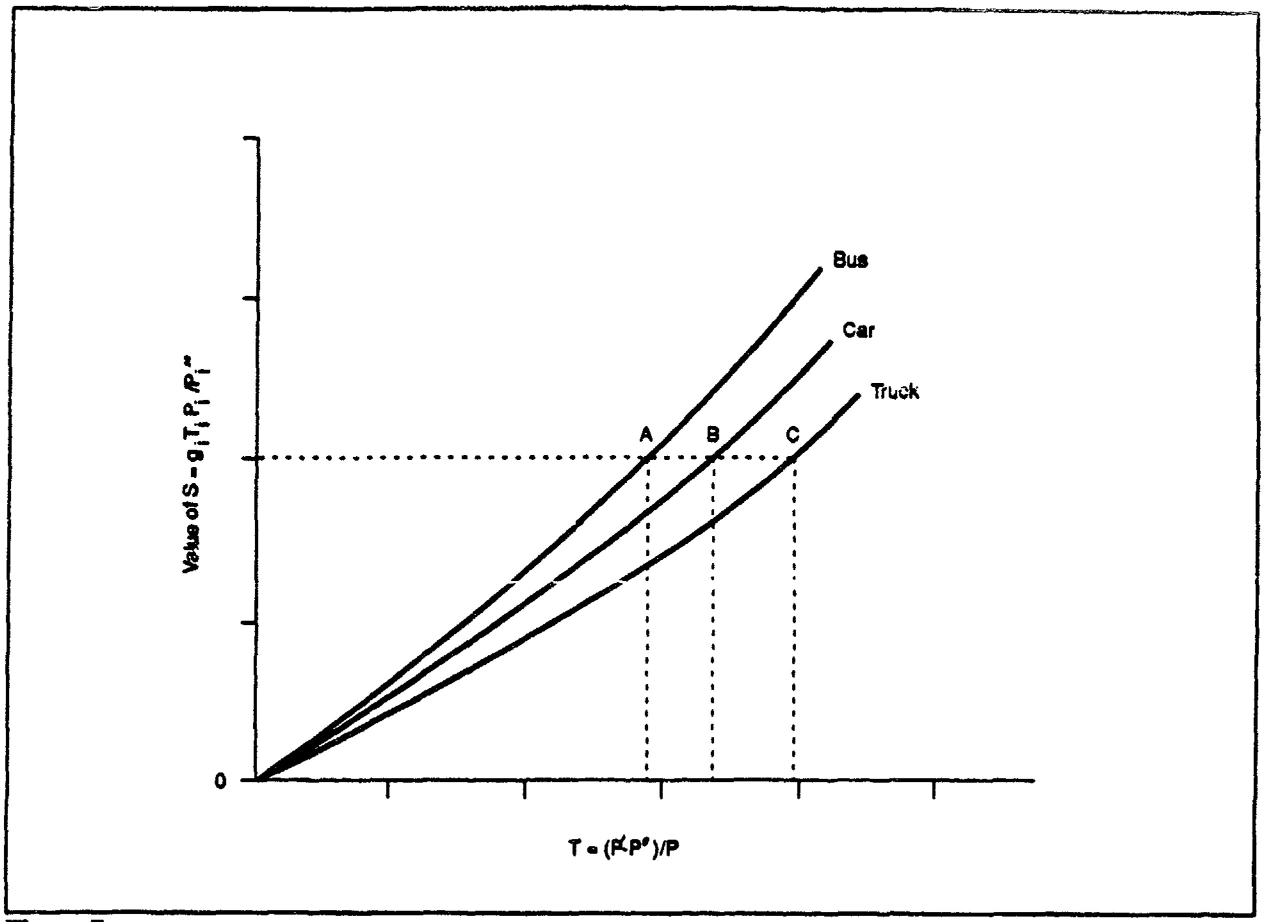

Figure 7: Using the Inverse Elasticity Rule to Compute the Mark-ups Needed to Cover Collective Common Costs

6.3 Is it Feasible to Charge for Congestion?

53. The optimum pricing model charges road users for the external congestion costs they impose on other road users. It is worth noting that the avoidable cost methodology outlined in previous sections also charges road users for some of the congestion they incur. Expenditures on expanding capacity (Table 2, column 1, item (vii)), which amounted to an estimated $19.60 million in 1982, are charged to road users as an avoidable cost on the basis of the road space they occupy (measured in terms of PCE km). These congestion charges are nevertheless too low (i.e., the costs currently charged to them, $19.60 million, are less than the $34.18 million [the sum of items (viii) and (ix) in Table 2, column 2] implied by the optimum pricing model). Furthermore, since motorists are only aware of the private costs they incur when making a journey, it would be more economically efficient to levy an explicit congestion charge to ensure they consciously paid for the entire social costs their journey imposed on others. It is also essential, on both distributional and economic efficiency grounds, to charge congestion against the specific road users who cause it, rather than to average it over the entire road network and over all users. This is particularly relevant with regard to the distinction between urban and rural road users. Most road congestion occurs in urban areas and averaged congestion charges will generally charge urban road users far too little and rural road users far too much.20/ Finally, when there are physical and/or environmental constraints which prevent road capacity being expanded -- even though such expansion may be economically justified — it will usually be desirable to use an explicit charging mechanism to help ration scarce road space.

54. However, although there is a strong case for introducing explicit congestion charges, the literature makes little attempt to identify: (i) the causes of road congestion (and hence the efficacy of road pricing); (ii) the extent of congestion (i.e., is it pervasive, or only confined to selected cities in some countries); and (iii) whether it is feasible and cost-effective to charge for congestion (see for example, Churchill, 1972; Newbery, et al, 1985; Walters, 1968). Low speeds in urban areas are only partly attributable to the presence of other vehicles. In most cities in developing countries, vehicle speeds are significantly influenced by the configuration and state of the road network, the presence of mixed traffic (pedestrians, hand-carts, head-loading, cycles, three-wheelers, etc.), parked vehicles and encroaching road-side activities. Under these circumstances, road pricing will have less effect on vehicle speeds than,

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20/ In Tunisia, congestion costs were averaged over the entire road network and then added to the road user charge. This resulted in urban peak-period car users paying less than one-eighth of the congestion costs they imposed on other motorists, while rural car users (accounting for over 60 percent of car veh km), paid nearly ten times these costs (Newbery, et al, 1988, Tables 3 and 7). It is not intuitively obvious that such gross averaging, even when appropriately weighted (Heady, 1989, Appendix Model 4), improves economic efficiency.

say, implementing a broad package of measures including traffic management, minor road improvements and traffic restraint.

55. It is likewise doubtful whether road congestion — in the sense of vehicles interfering with other vehicles — is a universal phenomenon. Work currently underway at the World Bank has identified two main types of city. The first are those where road congestion could be virtually eliminated by introducing simple traffic management measures (improved maintenance, road-signing and enforced traffic regulations) and minor road improvements (junction improvements, stopping and parking bays and relief roads). In other words, the congestion in these cities is mainly self-inflicted and attributable to the poor performance of the road agency. Most cities in developing countries fall into this category. In these cities, combined traffic management and minor road improvements are the most cost-effective ways of dealing with road congestion. Second, there are a limited number of cities in the Bank's main borrowing countries where road congestion is so serious that traffic management and minor road improvements need to be supplemented by explicit measures of traffic restraint. In general terms, there are only two cities in Africa which currently fall into this category (Lagos and, to a more limited extent, Nairobi), five in Asia (Bangkok, Bombay, Jakarta, Manila and Seoul), six in Latin America (Buenos Aires, Bogota, Mexico City, Rio de Janeiro, Sao Paulo, and Santiago) and five in the World Bank's Europe, Middle East and North African region (Algiers, Budapest, Cairo, Istambul, and Tunis). Serious congestion, requiring explicit traffic restraint measures, is therefore limited to a relatively small number of developing countries.

56. Charging for road congestion in developing countries is also quite difficult. There are clearly socio-political difficulties. This explains why Singapore (World Bank, 1986, Box 1) is the only city with a scheme in operation, although Hong Kong has experimented with one and Stockholm in Sweden is in the final stages of planning to introduce one in 1991 (designed to reduce both congestion and pollution). There are also implementation difficulties related to the characteristics of the road network. It is fairly easy to devise ways of charging vehicles travelling to and from the city centers in Bombay and Lagos (in both cases, vehicles must use one of three arterial corridors for part of their journey). On the other hand, it is considerably more difficult to devise ways of doing so in cities like Jakarta, Manila and Bangkok which are more spread out and experience local congestion in several locations.

57. Finally, congestion charging is relatively expensive and can be difficult to administer. The simplest method is to establish a cordon and to charge vehicles as they cross it. This could be done in cities like Bombay and Lagos where the layout of the city lends itself to such treatment. A cordon, or toll ring, is nevertheless relatively expensive. The cost of implementing the proposed toll ring in Oslo is estimated at $40 million, with annual operating and maintenance costs of $17 million. The area licencing scheme in Singapore is much simpler and less expensive. Vehicles must display a license in the restricted zone (there is no need for toll booths), but this makes it more difficult to administer. Even in a well-disciplined society like Singapore the cost of administering and enforcing the Singapore scheme are nearly $1.6

million per year. This represents a substantial investment at the city level in a developing country.

58. The other alternative, electronic road pricing (ERP), is relatively easy to administer, but is also expensive to install and difficult to maintain. Initial installation costs for an electronic number plate system in Hong Kong were estimated as $31 million for 210,000 vehicles with an annual operating cost of $2.6 million. In Cambridge, U.K., where a smart-card system has been proposed, the estimated costs of installation are roughly $50 million for 250,000 vehicles with an annual operating cost of $10 million to cover enforcement, servicing of equipment and installation of metering devices on annual additions to the vehicle fleet. Maintenance in developing countries is also a problem and, since the electronic number plate system debits the car owner's bank account, the rudimentary nature of personal banking in developing countries poses further difficulties.

59. An added complication is that congestion charges can also weaken financial discipline. The amount of congestion is a function of both road traffic and the physical configuration of the road network and the way it is managed. It follows that there are a variety of potential interventions — the improved traffic management and minor road improvements referred to in para. 55 — which can go some distance towards lowering congestion costs. Conversely, there are a number of current interventions which, if not actively administered (e.g., repair of traffic lights, enforcing traffic regulations, controlling road-side land use, etc.), will result in more congestion than necessary. The amount of congestion is not determined exogenously; it is partly determined by the performance of the road agency. It follows that, if the revenue from congestion charges accrues to the road agency, it will have little incentive — other than possible public indignation — to actively intervene to reduce congestion. Congestion charges should therefore be administered as a pure tax and collected by the government (which also has little incentive to intervene, since intervention would reduce government tax revenues).

60. The overall conclusions are therefore that: (i) serious road congestion, warranting explicit interventions to restrain traffic in the interests of economic efficiency, is fairly limited in developing countries; (ii) where there is serious congestion, it makes sense to introduce congestion charges to ration scarce road space; (iii) methods of charging for congestion are limited; and (iv) the charging instrument selected will depend on the nature of the city and its road network, the administrative complexity of the charging method, its maintenance requirements and its affordability. Simple cordon pricing schemes are likely to be the preferred solution in cities like Bombay and Lagos, while electronic methods would be relatively more appropriate in cities like Bangkok, Mexico City and Seoul. Furthermore, to the extent that congestion caused by motor vehicles is limited in developing countries vis-à-vis the developed world, congestion charges will make little contribution to the fixed costs of the road network in most countries and only a small contribution in those countries experiencing serious road congestion.

VII. APPLYING THE PRICING MODEL

61. The above avoidable cost methodology, together with the inverse elasticity rule, can now be used to calculate a set of road user charges for Tunisia. The price elasticities have been taken from Annex 2 and are equal to -0.6, -0.7 and -0.5 for car, bus and truck respectively (the figure for truck being the mid-point between -0.9, representing strong inter-modal competition, and -0.1, representing no inter-modal competition). The supply elasticities have been estimated from the slope of **BC** in Figure 6; the values for car, bus and truck are 46.61, 34.82 and 13.21 respectively. In other words, **BC** is fairly elastic. The calculations are set out in Table 5 which shows, in column 21, the resulting user charges and, in column 22, the revenues which would result from levying such charges.21/ The total revenues generated by the user charges, $91 million (which appear in Table 5 as $91.8 million due to rounding), correspond to the total expenditures set out in Table 2. The user charges vary from 0.52 cents per veh km for cars (gasoline) to 2.71 cents per veh km for buses and 12.70 cents per veh km for articulated trucks.

62. Table 6 compares the results from the avoidable cost methodology with the existing user charges in Tunisia (shown in column 7). It does not include the user charges recommended by Newbery, et al (1988), since the over-estimation of congestion costs would have caused these charges to generate $285.0 million, rather than the more modest figure of $54.86 given in Table 2, column (2). Table 6 includes three comparisons. The first set of user charges (column 1) correspond to the ones derived in Table 5 and are designed to cover all avoidable costs by generating total revenues of $91.6 million. The next two sets were designed to generate $385.7 million, these being the revenues generated by current user charges.22/ The first of these sets, column 3, has been calculated on the same basis as those set out in column 1. In other words, the difference between the $91.6 million generated by the user charges set out in column (1) and the $385.7 million generated by those set out in column (7), has been treated as a collective common cost and recovered from all users using the inverse elasticity rule. The second set, column (5), has treated the difference between the $91.6 million and the $386.7 million as a pure tax and, following the procedure adopted by Newbery, et al (1988), has recovered these additional collective common costs from passenger vehicles only (the user charges for vehicle types 3 to 6 and 8 have been kept the same as in column (1)).

21/ Table 5 has been laid out as a Lotus spread-sheet. The inverse elasticity rule is applied by choosing a cell well away from the table, say AS35, to represent S. This cell is then set equal to the initial guessed value of S. The cells in column 19 are set equal to (AS35/g_i), with g_i representing the appropriate price and supply elasticities for that type of traffic. Column 20 is then set equal to (col. 19·col. 18). The value of AS35 is then altered iteratively until the total of column 22 equals the total revenues required.

22/ The government in Tunisia collected about $200 million in road user charges during 1982 (World Bank and International Road Federation statistics). The higher figures of $285 million and $386 million given in Newbery et al (1988), suggest: (i) the VOC model used in Tunisia contains some bias; and/or (ii) there were important exemptions (e.g. of diplomatic and government vehicles); and/or (iii) the collection of road user charges was subject to significant levels of avoidance, evasion and leakage.

Table 5. Calculation of User Charges Using Avoidable Cost Principle and the Inverse Elasticity Rule: Tunisia, 1982

(c/veh km and $ million)

	Vehicle Characteristics				Usage of Road Network							Avoidable and Common Costs (c/veh km)										Total User Charge Revenue
		PCEs			Veh km (mill)			PCE km (mill)				Variable Costs		Grouped Common			Sub-Total		Common Costs		GRAND TOTAL	
Vehicle Type	VOCs, economic (c/km)	I-U	Urban	ESAs	I-U	Urban	Total	I-U	Urban	Total	ESA km (mill)	All vehs	Hvy vehs	Hvy vehs	I-U	U	User Chge	Chge + VOCs	Mark-up (%)	Mark-up (actual)		($, mill)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Car Gasoline	8.79	1.00	1.00	0.0001	1404	880	2284	1404	880	2284	0.2	0.08	0.00	0.00	0.07	0.13	0.28	9.07	0.03	0 24	0.52	11.8
Car Diesel	6.44	1.00	1.00	0.0001	464	291	755	464	291	755	0.1	0.08	0.00	0.00	0.07	0.13	0.28	6.72	0.03	0.18	0 46	3.4
Utility	12 44	1.00	1.00	0.0080	1721	851	2572	1721	851	2572	20.6	0.08	0.01	0.00	0.07	0.13	0.29	12.73	0.03	0.39	0.68	17.5
Light Truck	30.37	1.50	1.50	0.0920	441	218	659	662	327	989	60.6	0.08	0.09	0.03	0.10	0.19	0.51	30.88	0 03	0.95	1.45	9.6
Medium Truck	32.37	1.70	2.00	0 5800	161	16	177	274	32	306	102.7	0.08	0.59	0 21	0.11	0.26	1.26	33.63	0.03	1.03	2.30	4.1
Hvy Sgle Truck	39.13	2.00	2.50	2.6000	204	20	224	408	50	458	582.4	0.08	2.66	0.96	0.13	0.32	4.16	43.29	0.03	1.33	5.49	12.3
Hvy Tandem Tck	39.13	2.00	3.00	5.3800	12	1	13	24	3	27	69.9	0.08	5.50	1.99	0.13	0.39	8.09	47.22	0.03	1.45	9.54	1.2
Artic Truck	75.78	2.00	3.00	6.8000	133	7	140	266	21	287	952.0	0.08	6.95	2.52	0.13	0.39	10.07	85.85	0.03	2.64	12.70	17.8
Bus	62.38	2.00	3.00	0.4900	125	63	188	250	189	439	92.1	0.08	0.50	0.18	0.13	0.39	1.29	63.67	0.02	1.42	2 71	5.1
Special Vehicle	62.38	1.50	1.50	0.4900	220	78	298	330	117	447	146.0	0.08	0.50	0.18	0.10	0.19	1.06	63.44	0.03	1.95	3.01	9 0
Totals					4885	2425	7310	5802	2761	8563	2026.6								Total User Revenue	40.2		91.8

Notes: Heavy single-axle trucks have the same VOCs as heavy tandem-axle trucks, and special vehicles have the same VOCs as buses.
Source: (Newbery, et al, 1988)

63. The justification for the latter procedure is that freight transport, being an intermediate good, should not be subjected to any form of pure taxation (Newbery, et al, 1988, pp. 37-38).23/ It is not clear these principles are applicable in a developing country like Tunisia. Quite apart from the theoretical conditions which underlie the proposition — there are constant returns to scale and perfect competition — the principle is only applicable in countries with well-developed tax systems (ideally those operating a value added tax system) with broad tax bases and where most final sales bear tax (Myles, 1989). In countries like Tunisia, with narrow tax bases and weak tax administration, it is often not possible to tax all final goods and services. There is then a strong argument for levying positive taxes on intermediate goods and services as a means of taxing final sales indirectly.

Table 6. User Charges Calculated Using Avoidable Costs Compared with Those Used in Tunisia (Cents/veh km and $, million)

	From Table 5		Higher Revenues				Current Charges	
			Mark-up Applied to All Vehicles		No Pure Taxation of Freight Vehicles			
Vehicle Type	User Charge (c/veh km) (1)	Total Revenue ($,mill) (2)	User Charge (c/veh km) (3)	Total Revenue ($,mill) (4)	User Charge (c/veh km) (5)	Total Revenue ($,mill) (6)	User Charge (c/veh km) (7)	Total Revenue ($,mill) (8)
1 Gasoline	0.52	11.8	2.25	51.4	7.91	180.8	10.59	241.9
1 Diesel	0.46	3.4	1.74	13.1	5.94	44.8	5.26	39.7
2 Utility	0.68	17.5	3.54	91.0	0.68	17.5	0.59	15.2
3 Light T	1.45	9.5	8.38	55.2	1.45	9.5	1.77	11.7
4 Medium T	2.30	4.1	9.84	17.4	2.30	4.1	2.28	4.0
5a Hvy Sgle T	5.49	12.3	15.20	34.0	5.49	12.3	2.91	6.5
5b Hvy Tandem	9.54	1.2	20.13	2.6	9.54	1.2	3.02	0.4
6 Artic	12.70	17.8	31.96	44.7	12.70	17.8	7.50	10.5
7 Bus	2.71	5.1	13.18	24.8	47.22	88.8	11.48	21.6
8 Special	3.01	8.9	17.24	51.4	3.01	8.9	11.48	34.2
Total Revenue (a)		91.6		385.7		385.7		385.7

64. The relevant comparisons in Table 6 are therefore between columns 3 (all vehicles charged according to the same avoidable cost methodology) and 5 (no pure taxation of freight

23/ Newbery, et al, set the charges on trucks equal to marginal costs. In other words, trucks made no contribution either to fixed costs, or to pure taxation. This may be valid in an economy where all sectors charge marginal costs, but is not valid in Tunisia where the railways (which mainly carry freight) have to recover all their costs from users.

vehicles) on the one hand and column 7 on the other (the current user charges used in Tunisia). There are significant differences between columns 3 and 7, but less difference between columns 5 and 7. When the mark-ups are applied to all vehicles they result in lower charges for cars, higher charges for trucks and roughly the same charge for buses. Without pure taxation of freight vehicles, the charges for most vehicles are roughly the same. They are, nevertheless, much higher for buses, lower for gasoline cards and higher for heavy trucks.

VIII. OTHER ISSUES AND CONCLUSIONS

65. There are, as mentioned in the introduction, several other issues relevant to charging for roads which have not been dealt with in the present paper. It has not dealt with distributional issues (i.e. the way user charges affect income distribution and what to do about it), fiscal considerations (i.e., what contribution the road sector should make to the government's overall fiscal revenues), or with the question of which charging instruments to use and how to charge for accidents, noise, air pollution and other externalities. It has also ignored, other than in relation to congestion charges, the important relationship between the choice of pricing strategy and the impact this has on management incentives and hence on the costs of supplying road services. These are all important issues which, though not covered in the present paper, need to be addressed when designing road user charges.

66. The above analysis has, however, pointed to several important conclusions for policies on charging for roads.

(i) It is unrealistic to assume, for the road network as a whole, that there are constant returns to scale in road construction and in road use. Road maintenance costs also contain a number of fixed costs which do not vary with traffic (up to half the annual expenditures and road maintenance are usually fixed).

(ii) Roads cannot be smoothly adjusted to traffic, so that marginal costs for the entire road network are significantly lower than average costs in most developing countries. Congestion charges will therefore generate insufficient revenues to cover all fixed costs. Congestion in a few large cities is nevertheless sufficiently serious to warrant congestion charges. While this may help to recover the fixed costs of congested urban roads, the revenues are unlikely to cover the fixed costs of the road netwo.k as a whole.

(iii) Under the above conditions, optimal road user charges will generate insufficient revenues to cover the capital costs of the road network and total expenditures on road maintenance.

(iv) Since it is not economically efficient to bridge the financing gap by cutting back on maintenance, it has to be bridged by collecting the required revenues by taxing beneficiaries, raising user charges, or by mobilizing additional general tax revenues. Taxes on beneficiaries were not examined in the present paper, but are usually the preferred method of charging for residential streets and rural access roads. For roads carrying significant volumes of traffic, the choice is generally between user charges and general tax revenues. The costs of mobilizing additional general tax revenues are, however, high and, given the generally low price elasticity of demand for roads, it is nearly always more economically efficient to collect the required revenues from road users.

(v) While it is generally agreed that marginal costs, corresponding to variable costs, should be the floor below which user charges should never fall, there is no reason to stop at marginal costs. An important group of costs are avoidable, attributable to individual groups of users (though not to the individual users themselves) and it seems reasonable — on grounds of simplicity, equity and political expediency — to charge these costs against each individual user group. The remaining costs, although also avoidable, are common to all users and, to minimize loss of consumer surplus, should be charged to them using the inverse elasticity rule.

(vi) There are significant differences between the user charges calculated using the avoidable cost methodology and current user charges in Tunisia.

Annex 1

Calculation of Congestion Costs for Tunisia

1. In equilibrium, road user charges are equal to the optimum congestion charge plus variable road maintenance costs. When the congestion charge exceeds the costs of expanding road capacity, capacity should be expanded until the road is again back in equilibrium (Walters, 1968, p 31). In other words, roads should be expanded when the sum of marginal congestion costs equals the annualized costs of expanding road capacity. Congestion costs should therefore always be less than the annualized costs of expanding road capacity unless there are physical or environmental constraints which allow congestion to rise beyond the point where normal benefit/cost analysis justifies additional investment. This Annex examines the costs of congestion in Tunisia on: (i) inter-urban roads; and (ii) urban roads.

Inter-Urban Roads 1/

2. The nature of the inter-urban road network in Tunisia is summarized in Table A.1, which shows the amount of traffic using roads of different widths. A simple rule-of-thumb is that narrow roads (less than 5.5 m wide), carrying more than 2,000 vehicles per day, usually require widening (i.e. widening will usually be economically justified), while two-lane roads carrying more than 5,000 vehicles per day will usually justify improvement to dual-carriageway standard. In other words, 58 km of roads shown in Table A.1 may justify widening and 141 km may justify expansion to dual-carriageway standard. In Tunisia, road widening costs about $50,000 per km (at 1982 prices), while construction of a dual-carriageway road, effectively adding a second two-lane road to an existing one, costs about $280,000 per km (excluding major structures).

3. In addition, as shown in Table A.2, there is measurable congestion on a further 1,313 km of 5.5 m wide road (971 + 342 km), on 1,300 km of 5.5-7.5 km road (615 + 527 + 158) and on 71 km of road wider than 7.5 m. If these sections of road are weighted according to the marginal congestion costs shown in Table A.2 (using as denominators, the threshold values of 0.32, 0.43 and 0.35 respectively shown in the table), the equivalent congested road length becomes 467, 326 and 72 km respectively. Applying the figure of $50,000 to the 467 km of road less than 5.5 m wide, and $280,000 to the remaining 398 km, results in a total cost of $134.8 million. This translates into an annualized cost, using an 8 percent discount rate and a 20 year repayment period, of $13.68 million. The annual costs of congestion on inter-urban roads should therefore not exceed this figure. This estimate compares favorably with the figure of $12.4 calculated by Newbery, et al, 1988.

1/ Sources: Paterson, 1985; Newbery, 1986.

Urban Roads 2/

4. Urban traffic conditions in Tunisia are summarized in Table A.3. Traffic flows are not particularly high — except for three sections of road (two in Sfax and one in Tunis) carrying over 5,000 vpd — although some narrow roads are carrying traffic volumes high enough to cause some congestion. Until 1982, little investment was undertaken to relieve urban road congestion, other than on modest traffic management schemes. By 1984, however, congestion had become a serious problem in parts of Tunis and Sfax and a Highway Master Plan was prepared to help reduce urban road congestion. This resulted in an investment program costing $34.31 million, at 1983 prices, with an economic rate of return of 36 percent. Although it is difficult to measure congestion, the Master Plan estimated that, with the amount of traffic expected in 1986, the total amount of travel time would amount to about 37,817 PCE hrs during the six-hour daily peak period and that vehicles would be travelling at an average speed of 19.5 km/hr. If there was no congestion — and traffic speeds were determined only by the configuration of the road network, pedestrian activity, parking and other sources of road-side friction — traffic speeds could rise to about 30 km/hr in the central city area and 45 km/hr in the suburbs. In Singapore, the area licensing scheme introduced in 1975, only managed to increase travel speeds by about 20 percent (World Bank, 1986, Box 1). Average speeds could therefore rise from 19.5 km/hr to about 35 km/hr, saving about 16,775 PCE hrs per day (37,817 - 21,042). When this time is valued at the average time-cost of $3.06 per hour (vehicle operating costs, plus the value of personal travel time), and expanded by 300 to give the equivalent annual cost, it results in a total cost of $15.40 million.

5. The estimate of $15.40 million p.a. in 1986 looks reasonable in relation to the 36 percent rate of return earned on urban road investments costing $34.31 million at 1983 prices. The costs of urban congestion in Tunis (i.e., the sum of the marginal congestion costs) would have been somewhat lower in 1982, but a rough figure of $15 million does not appear unreasonable. However, there would also have been some congestion in Sfax (population 310,000 compared to 1.2 million in Tunis). On the assumption that this congestion amounted to about a third of that in Tunis, total urban congestion in Tunisia probably amounted to about $20 million in 1982. This is much lower than the figure of 122 million estimated by Newbery, et al, 1988. If the costs of congestion really were as high as $122 million, it would justify spending about $1,202 million (using an 8 percent discount rate and 20-year repayment period) to relieve traffic congestion. This looks implausible compared to the investment program of only $34.31 million which was found to be economically justified in Tunis.

2/ Sources: World Bank, 1984.

Table A 1.1: Length of the Classified, Inter-urban Paved Road Network
(Km, 1982)

Traffic Class	AADT (Veh/day)	Peak PCE/hr	Road Length %	Width of Road (meters) <5.5	5.5-7.5	>7.5	All
T1)			16.1	971	258		1,229
T2)	<1,000	-	45.6	2,332	1,114	35	3,480
T3	1,000	112	21.2	971	615	32	1,618
T4	2,032	227	11.5	342	527	9	878
T5	3,750	419	3.7	54	158	71	282
T6)	8,525	953					
T7)	12,000	1,342	1.9	4	87	54	145
			100.0	4,674	2,758	200	7,632

Sources: Road lengths (Paterson, 1985, Table 1.5), AADT and Peak Flows (Newbery, 1986, Tables 5 and 7).

Table A 1.2: Degree of Congestion and Length of Inter-Urban Road Affected by Congestion
(Vehicle hrs/100 PCE km)

Traffic Class	AADT (veh/day)	Peak PCE/hr	Road Length %	Width of Road (meters) <5.5 m	5.5-7.5 m	>7.5 m
T1)			16.1	0.00	0.00	0.00
T2)	<1,000	-	45.6	0.00	0.00	0.00
T3	1,000	112	21.2	0.08	0.05	0.00
T4	2,032	227	11.5	0.16	0.07	0.00
T5	3,750	419	3.7	0.32	0.15	0.09
T6)	8,525	953		-	0.43	0.22
T7)	12,000	1,342	1.9	-	0.56	0.35
congested Roads (km) (a)				467	326	72

Notes: (a) Road length, from A 1.1, weighted by degree of congestion. The marginal congestion costs which justify expanding road capacity have been taken as 0.32, 0.43 and 0.35 respectively.

Sources: As for Table A 1.1; Marginal Congestion Costs (Newbery, 1986, Table 9).

Table A 1.3: Summary of 1982 Urban Road Conditions in Tunisia

AADT (veh/day)	Length of Road (km)	Length of Road per cent	Amount of Travel vkm p. a.	Amount of Travel per cent	Notes
< 2,000	380	21.0	631	24.7	
2,000 - 2,999	796	44.1	614	24.0	
3,000 - 3,999	436	24.1	809	31.7	
4,000 - 4,999	116	6.4	169	6.6	
5,000 - 5,999	26	1.4	95	3.7	One road in Sfax.
> 6,000	52	2.9	236	9.2	One road each in Tunis and Sfax.
	1,806		2,554		

Sources: (Paterson, 1985, Tables 1.6, 1.7 and 1.8).

Recent Estimates of the Price Elasticity of Demand for Transport

1. The following tables summarize seventy estimates of the price elasticity of demand for transport published in recent journal articles (Oum, et al, 1990). The estimates are drawn from several countries: 32 studies in U.S.A., 8 in Canada, 8 in U.K., 3 in the rest of Europe, 7 in Australia and New Zealand, 2 in India and Pakistan and 8 in other countries. They cover many different transport modes and market situations, and employ different statistical methods and data bases.

2. Tables A3.1 and A3.2 summarize the ordinary own-price elasticities of demand for passenger and freight transport. Table A3.1 also presents mode choice elasticities which can be linked to ordinary demand elasticities if sufficient information is available. These mode choice elasticities are not directly comparable to the ordinary own-price elasticities. Mode choice own-price elasticities are less than ordinary own-price elasticities and this has been taken into account in the "most likely" range of ordinary elasticities.

3. Table A3.3 summarizes information on the ordinary own-price elasticity of demand for gasoline, while Table A3.4 presents selected cross-price elasticity estimates from studies with a relatively high degree of aggregation (they are thus more representative of average conditions).

4. It was not possible to categorize the estimates into *short run* or *long run* elasticities. Most studies make no reference to the implied time horizon. As a rough guide, cross-sectional data sets are thought to represent long run relationships, whereas time series data (especially if monthly or quarterly data are used) reflect short run demand relationships. However, this is not an unambiguous guide and panel data sets (combined cross-section and time series data) further complicates interpreting the time dimension of elasticity estimates. The *most likely* range of elasticities is therefore ambiguous concerning the implied time horizon, although the upper range probably comes closest to being a long run rather than a short run elasticity.

5. Most of the estimates presented relate to developed countries, reflecting the availability of data, research resources and domicile of the researchers. The elasticity estimates are nevertheless thought to be relevant to developing countries as well. But since intermodal competition is generally less intense in developing countries, this tends to make transport demand more inelastic, although for passenger transport the lower income levels in such countries may partly offset this effect.

6. In the case of freight transport, the incidence of intermodal competition is more significant. The studies of road and rail are all based on data from the U.S. and Canada where most freight traffic is subject to strong intermodal competition. The aggregate demand

elasticities (-0.8 for rail and -0.9 for truck) must therefore be regarded as the upper limit of the demand elasticity when there is strong intermodal competition. When there is no competition, the derived price elasticity is likely to provide a better estimate of the elasticity of demand for transport. Provided the elasticity of supply approaches infinity, the derived elasticity is equal to $e = f \cdot e'$, where e represents the derived elasticity of demand for transport, e' is the demand elasticity for final goods and services and **f** is the fraction of the demand price spent on transport (Bennathan and Walters, 1969, Technical Appendix). In the case of road transport, **f** amounts to about 10 to 20 percent of the delivered price and e' generally varies from -0.4 (food products) to -0.8 (miscellaneous goods and services) (Chetty and Haliburn, 1982). Since the low value of **f** corresponds to the low value of e, the derived price elasticity of demand for freight transport, corresponding to the demand elasticity without any intermodal competition, is thus about -0.04.

Table A2.1: Elasticities of Demand for Passenger Transport
(All elasticity figures are negative)

	RANGE SURVEYED			
Mode	**Market demand elasticities**	**Mode choice elasticities**	**Most likely range**	**No. of studies c/**
Air: a/				
Vacation	0.40-4.60	0.38	1.10-2.70	8
Non-vacation	0.08-4.18	0.18	0.40-1.20	6
Mixed b/	0.44-4.51	0.26-5.26	0.70-2.10	
Rail: intercity				
Leisure	1.40	1.20	1.40-1.60	2
Business	0.70	0.57	0.60-0.70	2
Mixed b/	0.11-1.54	0.86-1.14	0.30-1.18	8
Rail: intracity				
Peak	0.15	0.22-0.25	0.20-0.40	2
Off peak	1.00	n.a.	≤1.00	1
All day b/	0.12-1.80	0.08-0.75	0.1 00.70	4
Automobile:				
Peak	0.12-0.49	0.02-2.69	0.10-0.70	9
Off peak	0.06-0.88	0.16-0.96	0.20-1.10	6
All day b/	0.00-0.52	0.01-1.26	0.10-1.10	7
Bus:				
Peak	0.00	0.03-0.58	0.10-0.70	6
Off peak	1.08-1.54	0.010.69	0.10-1.10	3
All day	0.10-1.62	0.03-0.70	0.10-1.30	11
Rapid transit:				
All day b/	0.05-0.86	n.a.	0.20-0.90	5
Transit system:				
Peak	0.00-0.29	0.1	0.10-0.30	4
Off peak	0.32-1.00	n.a.	0.30-0.50	3
All day b/	0.01-0.96	n.a.	0.10-0.70	10
Others:				
Minibus	n.a.	n.a.	-	1
Aircraft landing	0.06-0.56	n.a.	-	1

a/ The distinction between vacation and non-vacation routes are rather arbitrary in most studies. This may partly account for the very wide range of elasticity estimates reported.
b/ This category includes studies that do not make the distinctions.
c/ The number of studies in the column do not sum to the total because some studies report more than one set of estimates.
n.a. = not available

Table A2.2: Elasticities of Demand for Freight Transport
(All elasticity figures are negative)

Mode	Range Surveyed	Most Likely Range	No of studies
Rail:			
Aggregate Commodities	0.60-1.52 (0.09-1.79)	0.40-1.20	4
Assembled Automobiles	0.65-1.08	0.70-1.10	2
Chemicals	0.39-2.25 (0.66)	0.40-0.70	3
Coal	0.02-1.04	0.10-0.40	2
Corn, wheat, etc.	0.52-1.18	0.50-1.20	3
Fertilizers	0.02-1.04	0.10-1.00	1
Foods	0.02-2.58 (1.36)	0.30-1.00	9
Lumber, pulp, paper, etc.	0.05-1.97 (0.76-0.87)	0.10-0.70	7
Machinery	0.61-3.55 a/	0.60-2.30	3
Paper, plastic and rubber products	0.17-1.85	0.20-1.00	4
Primary metals and metallic products	0.02-2.54 a/ (1.57)	1.00-2.20	5
Refined petroleum products	0.53-0.99	0.50-1.00	3
Stone, clay and glass products	0.82-1.62 (0.69)	0.80-1.70	4
Truck			
Aggregate commodities	0.05-1.34	0.70-1.10	1
Assembled Automobiles	0.52-0.67	0.50-0.70	1
Chemicals	0.98-2.31	1.00-1.90	2
Corn, wheat, etc.	0.73-0.99	0.70-1.00	2
Foods	0.32-1.54	0.50-1.30	3
Lumber, wood, etc.	0.14-1.55	0.10-0.60	3
Machinery	0.04-1.23	0.10-1.20	3
Primary metals and metallic products	0.18-1.36	0.30-1.10	3
Paper, plastic and rubber products	1.05-2.97	1.10-3.00	2
Refined petroleum products	0.52-0.66	0.50-0.70	3
Stone, clay and glass products	1.03-2.17 a/	1.00-2.20	2
Textiles	0.43-077	0.40-0.80	1
Air			
Aggregate commodities	0.82-1.00	0.80-1.60	3
Shipping: inland waterway b/			
Aggregate commodities	(0.74-0.75)	-	1
Chemicals	0.75	-	1
Coal	0.28	-	1
Crude petroleum	1.49	-	1
Grain	0.64-1.62	0.60-1.60	2
Lumber and wood	0.60	-	1
Non-metallic ores	0.55	-	1
Primary metal	0.28	-	1
Pulp and paper	1.12	-	1
Stone, clay and glass products	1.22	-	1
Shipping: ocean b/			
Dry bulk shipment c/	0.06-0.25	-	1
Foods	0.20-0.31	-	1
Liquid bulk shipment	0.21	-	1
General cargo	0.00-1.10	-	1

a/ The high elasticity estimates may reflect the mode's low market share of aggregate freight when using the translog cost function in estimation.
b/ There have been very few empirical studies on shipping, hence the elasticity estimates reported here should be interpreted with caution.
c/ These include coal, grain, iron ore and concentrates, etc.
Note: Figures in parentheses are mode choice elasticities.

Table A2.3: Elasticities of Demand for Gasoline
(All elasticity figures are negative)

Country	Range Surveyed	Most Likely Range	No of studies
Austria	0.25-0.27	-	1
Canada	0.11	-	1
Israel	0.25	-	1
U.K.	0.1-0.17	-	1
U.S.	0.04-0.21	-	1
West Germany	0.25-0.93	-	1
Multicountry Studies	0.20-1.37 a/	0.20-0.50	3

a/ Included in this range is a long-run elasticity estimate of 0.32-1.37

Table A2.4: Selected Estimates of Cross Elasticities
(Aggregate Data)

Authors	Modes	Cross Elasticities a/	Remarks
Oum (1979a)	Rail-truck	−0.10 to +0.14	Aggregate freight transport
	Truck-rail	−0.88 to +0.13	demand in Canada, cross
	Rail-waterway	+0.15 to +0.20	elasticities reported for
	Waterway-rail	+0.61 to +0.86	selected years between
	Truck-waterway	−0.23 to +0.03	1950-1974.
	Waterway-truck	−0.12 to +0.13	
Oum and Gillen (1983)	Air-bus	−0.02 to −0.01	Aggregate intercity
	Air-rail	+0.01 to +0.04	passenger transport
	Bus-air	−0.12 to −0.05	demand in Canada, cross
	Bus-rail	−0.47 to −0.21	elasticities reported for
	Bus-air	+0.08 to +0.51	selected years between
	Rail-bus	−1.18 to −0.17	1961-1976.
Oum (1989)	Rail-truck b/	−0.18 to +0.50	Interregional freight
	Truck-rail b/	−0.62 to +0.84	transport demand in
	Rail-Truck c/	−0.47 to +0.48	Canada.
	Truck-rail c/	−0.26 to +0.35	

a/ When the cross elasticity is negative, it means the two modes are competitors. Raising the price of one then diverts traffic to the other. When the cross elasticity is positive, the modes are complements (e.g., piggy-back road/rail traffic). Raising the price of one then causes both modes to lose traffic.
b/ Aggregate commodities.
c/ Fruits, vegetables and other edible foods.

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